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METHODS FOR IDENTIFYING AND EVALUATING THE NATURE AND EXTENT OF NON-POINT SOURCES OF POLLUTANTS

U.S. ENVIRONMENTAL PROTECTION AGENCY
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Agricultural, silvicultural, construction and mining activities contribute several pollutant substances to surface and groundwaters, and thus share with other activities the responsibility for protecting the quality of this country's water resources. These sources are diffuse in nature and discharge polluting substances to the water via widely dispersed pathways. The report describes the four activities of polluting, and assesses the nonpoint sources.

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FOREWORD

This report is issued under Section 304(e)(1)(A,B,C) of Public Law 92-500. This Section provides:

> "The Administrator, after consultation with appropriate Federal and State agencies and other interested persons, shall issue to appropriate Federal agencies, the States, water pollution control agencies, and agencies designated under Section 208 of this Act, within one year after the effective date of this subsection (and from time to time thereafter) ...information including guidelines for identifying and evaluating the nature and extent of non-point sources of pollutants resulting from --
>
> (A) agricultural and silvicultural activities, including runoff from fields and crop and forest lands;
>
> (B) mining activities, including runoff and siltation from new, currently operating, and abandoned surface and underground mines;
>
> (C) all construction activity, including runoff from the facilities resulting from such construction; ...."

This report, prepared under contract by Midwest Research Institute, Kansas City, Missouri, and Hittman Associates, Inc., Columbia, Maryland, for the Environmental Protection Agency, provides general information on methods of identifying and evaluating sources of pollutants associated with agricultural, silvicultural, mining and construction activities. It is intended to enable planners responsibile for developing regional water quality management plans to indentify and evaluate sources of pollutants and their effects on water quality in relevant planning areas. The application of the methods described must be ascertained on a case-by-case basis as regional differences can substantially affect the results obtained.

Russell E. Train
Administrator

EPA-430/9-73-014
OCTOBER 1973

METHODS FOR IDENTIFYING AND EVALUATING THE NATURE AND EXTENT OF NONPOINT SOURCES OF POLLUTANTS

U.S. ENVIRONMENTAL PROTECTION AGENCY
OFFICE OF AIR AND WATER PROGRAMS
WASHINGTON, D.C.

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TABLE OF CONTENTS

Page

1.0 Introduction 1

2.0 Summary Discussion 3

2.1 Introduction. 3
2.2 The Nature of Nonpoint Pollution from Agriculture, Silviculture, Mining, and Construction. 3
2.3 Models for Predicting Nonpoint Pollution. 18
2.4 Sources of Information Relevant to Assessment of Nonpoint Pollution. 24

References 31

3.0 Agriculture. 35

3.1 Introduction. 35
3.2 Sources of Pollution from Agriculture 35
3.3 Pollutant Transport 37
3.4 Extent of Pollution from Agriculture. 39
3.5 Prediction of the Nature and Extent of Nonpoint Pollution from Agriculture. 45

References 82

4.0 Silviculture 93

4.1 Introduction. 93
4.2 Silvicultural Activities. 94
4.3 Nature and Extent of Sources of Pollution from Silvicultural Activities. 100
4.4 Prediction of Pollution from Silvicultural Activities. 132

References 152

5.0 Mining 163

5.1 Introduction. 163
5.2 Nature and Extent of Pollution from Mining Activities. 163

TABLE OF CONTENTS (Concluded)

Page

5.3 Data Interpretation Aids and Prediction Methods Pertaining to Pollution Sources from Mining . . . 195

References 226

6.0 Construction 233

6.1 Introduction. 233
6.2 Types of Construction Activity. 233
6.3 Sources of Water Pollution. 234
6.4 Types of Pollutants 239
6.5 Methods of Pollutant Transport. 244
6.6 Quantification of Pollution from Construction Activities. 246

References 255

7.0 Acknowledgements 261

LIST OF FIGURES

Figure No.	Title	Page
2-1	A Hypothetical Hydrograph.	21
2-2	Hypothetical Hydrographs Showing Effects of Various Storm Types.	22
3-1	Typical Amounts of DDT (ppm) in the Environment.	41
3-2	Curves Showing the Relationship of Splash of Soil (E) to Infiltration Capacity for Four Soil Types	49
3-3	Nomograph for Probable Soil Loss Using Musgrave Equation	50
3-4	Soil Erodibility Nomograph	53
3-5	Slope--Effect Chart (Topographic Factor, LS)	54
3-6	Slope--Effect Chart (Topographic Factor, LS) for Slopes and Lengths Exceeding Those in Figure 3-5	55
3-7	Sediment Delivery Ratio vs Size of Drainage Area	59
3-8	Nomograph Solution of Equation 3-14.	62
3-9	Sediment Discharge Rating Curves for San Juan River at Bluff, Utah	63
3-10	Seasonal Flow-Duration Curves for San Juan River at Bluff, Utah	64
3-11	Sediment Yield vs Drainage Area for the Southwest.	67
3-12	San Ramon Creek at Walnut Creek, California, Relationship Between Discharge and Suspended Sediment Concentration	68
3-13	Walla Walla River Near Touchet, Washington, Relationship Between Discharge and Suspended Sediment Concentration (Generalized)	69
3-14	Depth-Density Relation of Reservoir Sediment	74
3-15	Sediment Load Variations in Lake Mead During 1955-1964.	77
3-16	Simplified Runoff Hydrograph and Sediment Load from Small Agricultural Watersheds	81
4-1	The Distribution and Fate of Chemicals in the Environment.	119
4-2	Lateral Movement of Spray Particles of Various Diameters Falling at Terminal Velocity in a 8 km/hr (5 mph) Crosswind.	121
4-3	Relative Mobilities of Pesticides in Subirrigated Columns of Soil.	123
4-4	A Nutrient Cycle for a Forest.	129

LIST OF FIGURES (Concluded)

Figure No.	Title	Page
4-5	Textural Triangle of Soils.	138
4-6	Average Net Solar Radiation Absorbed by Streams Between Latitudes 30N and 50N on Clear Days During Several Periods of Exposure to Different Solar Paths.	148
5-1	Nomogram I.	197
5-2	Nomogram II	198
5-3	Predicted Slope Distance Covered with Spoil Below Outcrop for Various Highwall Heights. . .	219
5-4	Predicted Slope Distance Excavated Above Outcrop for Various Highwall Heights.	220
5-5	Typical Cross-Section of Contour Strip Mine . . .	221

LIST OF TABLES

Table	Title	Page
2-1	Land Use Data.	4
2-2	Representative Rates of Erosion From Various Land Uses . . .	6
2-3	Relative Erosion From Various Land Uses: Nationwide	7
2-4	Public Agencies as Sources of Data for Identifying and Evaluating Nonpoint Source Pollution	25
3-1	Summary of Sediment Prediction Methods	47
3-2	Bed Load Correction Table.	65
3-3	Classification of Sediment Yield for Pacific Southwest . . .	70
3-4	Sediment Yield Levels and Their Ratings for a Watershed of 39 km^2 (15 mile^2) in Western Colorado.	72
3-5	Unit Weight of Sediment in Sediment Volume Computations. . .	75
3-6	Unit Weight of Sediment in Sediment Volume Computations. . .	76
4-1	Frequency of Forest Fires Necessary to Maintain Species for Unmanaged Forests.	99
4-2	Percentage of Soil in Logged Area Made Bare by Various Logging Systems in Washington and Oregon	106
4-3	Causes of Wildfires.	109
4-4	Pest Control Accomplishments in the United States, 1969. . .	116
4-5	Cover Factors for Woodland	134
5-1	Mine Drainage Classes.	168
5-2	Underground Mines in Urban Areas	174
5-3	Pennsylvania Bituminous Mining Drainage Cases.	180
5-4	Selected Information for Acid Mine Drainage Sources in Northern Appalachia.	183
5-5	Abandoned and Inactive Underground Mines in the U.S. as of 1966	187
5-6	Land Disturbed by Strip and Surface Mining in the U.S. as of January 1, 1965, by Commodity and State.	188
5-7	Rating of Environmental Effects of Discrete Coal Surface Mining and Reclamation Operations.	192
5-8	Estimated Environmental Effects of Coal Surface Mining . . .	194
5-9	Factors for Converting Concentration Data into Forms for Checking Anion-Cation Balance.	203

SUMMARY

Agricultural, silvicultural, construction and mining activities contribute several pollutant substances to surface and groundwaters, and thus share with other activities the responsibility for protecting the quality of this country's water resources. These sources are diffuse in nature and discharge polluting substances to the water via widely dispersed pathways. Procedures for ameliorating the pollution must accordingly deal with activities and materials which are spread over relatively large land areas.

The major pollutant is sediment, the soil materials which erode from the surface of the land and are transported to streams and reservoirs by runoff water. Cropland is the chief source of sediment on a total mass basis; 50% or more of the sediment deposited in streams and lakes is credited to agriculture. Construction and surface mining activities, however, yield large quantities of sediment in relatively small regions of impact; sediment from these sources can have a highly adverse impact on both the quality of water, and on costs of water supply and storm water management. Well managed forests are exceptionally free of erosion and sediment pollution, but soils in forests disturbed by natural disasters (fire) or by harvest of timber are erodible, highly so if timber harvest is poorly managed.

Mineral pollutants are a problem of substantial importance to the mining industry. Mineral pollution arises from contact of water with mining refuse and with ore and rock formations exposed by the mining activities. Acid drainage, though most popularly attributed to coal mining, is a common problem in this industry. The acid mine drainage is generated in large quantities; it can be a very serious problem to communities located near the source, and is a substantial economic and environmental burden to urbanized areas in heavily mined regions. In addition to acid and salinity or hardness minerals, mine drainage is a carrier, usually in trace quantities, of a number of mineral elements (lead, arsenic, zinc, cadmium, copper) which are a toxic threat at sufficiently high concentrations.

Nutrient elements, chiefly nitrogen and phosphorus, are emitted from agricultural lands as well as from the remainder of the rural areas on which rainfall or irrigation is sufficient to support plant and animal life. The rates of emission are greatest from lands managed for intensive production of crops and livestock. It is estimated that perhaps 1 million metric tons, of a total of 5 to 6 million metric tons of nitrogen lost to surface and groundwaters, are attributable to the use of fertilizers.

Pesticides are widely used in agriculture, less extensively in silviculture, construction, and mining. These may be transported to water resources by careless application, by spray drift, by runoff and by seepage or infiltration. The extent of the hazard depends greatly on the properties of the pesticide and the care exercised in its use.

Organic wastes are transported to streams chiefly in runoff water, and have essentially the same adverse effects as organic wastes of domestic and industrial origin. Crop debris, livestock wastes, waste petroleum products, forest litter, and numerous solid waste materials are included in this type of waste material. Organic wastes of animal and human origin are a source of biological pollutants, some of which are disease producing.

Thermal pollution--the elevation of temperature in surface waters--is of concern in silviculture, where removal of tree cover along stream banks exposes the water to the sun's rays.

The magnitudes of the impacts of these pollutants, from the four sources, vary in direct proportion to the quality of the management of specific activities within agriculture, silviculture, construction and mining. A terraced field is substantially less subject to erosion than is a field tilled up and down the slope. Well designed haul roads in silviculture and construction erode much less severely than unplanned roads; and strip mined areas returned immediately to an effectively reclaimed state cease to be significant sources of acid drainage, mineral pollutants and sediments. The extent of pollution from specific agricultural, silvicultural, construction and mining activities is therefore greatly affected by the care exercised by the forester, the farmer, the livestock operator, the mining industry, and the construction industry.

Planning for water quality management in watersheds and other planning regions can be effective only if the relationships involving inputs and outputs of various pollutants are understood, and if the effects of the pollutants on water quality can be reliably assessed. Further, it is essential that methods for predicting inputs and outputs be available to the planner. These predictive methods are available in varying degrees of usefulness and sophistication for sediment, thermal pollution and mine drainage, and are generally unavailable in useful form for pesticides, nutrients, heavy metals, biological pollutants, and organic wastes. A substantial and very useful fund of information and data is on hand for use in describing base-line characteristics of water quality planning regions, and for developing the rules of thumb, equations, nomographs and other predictive tools needed by the planner.

1.0 INTRODUCTION

The quality of this nation's water resources is a combined function of natural processes, and processes which are attributed to man's activities. Natural processes tend to be nondiscrete and diffuse, and create discharges to the environment not amenable to treatment; such processes and discharges are said to be nonpoint. Much of man's contribution to water quality derives from discrete, localized operations which generate point pollutional discharges amenable to isolation and treatment. Man is also a substantial originator of nonpoint discharges to the environment. Nonpoint sources of discharge for which man must accept responsibility include agriculture; mining; urban and rural construction, urban storm runoff; nonurban based recreational activity, i.e., camping, fishing and hunting; and silviculture. It is increasingly apparent that these and other nonpoint sources are a substantial deterrent to achievement of water quality goals. Accordingly, the Congress has decreed in the 1972 amendments to the Water Quality Act that specified nonpoint sources of pollution shall be characterized and plans formulated for amelioration of pollution originating from them.

The study reported herein was undertaken to provide documentation of presently available knowledge in four areas: silviculture, agriculture, mining, and construction. The body of knowledge of concern is the nature (kinds of pollutants, their sources, and their relative importance) and extent (the magnitude of pollutant emissions: quantities, concentrations) of nonpoint water pollution. Particularly important are factors which relate an emitted pollutant to its source, for the study is designed to assist the planner/engineer in evaluating nonpoint sources of pollutants and their effects on water quality in regional planning areas.

This report presents results of a 3-month study directed to this need. Specific objectives of the program were:

1. To provide descriptions of nonpoint sources information relevant to water pollution problems, including the nature of sources, type of pollutants, relative importance of pollutants from each source, and pollution loads related to natural and operational factors.

2. To determine methods, techniques, and procedures that can be used for identifying, measuring, and evaluating the nature and extent of the pollutants from nonpoint sources.

3. To provide analyses of the effect of nonpoint sources pollutants on water quality management.

Information derived from existing reports, papers, handbooks, and from concerned researchers and private and governmental agencies served as the basis for the study. Physical, chemical, and biological aspects of water pollution were considered.

The following were investigated as sources of pollution:

1. Agriculture: croplands, grasslands, and livestock.

2. Silviculture: forest culture, harvesting, and logging practices.

3. Mining: new, current, and abandoned surface and subsurface mines, and associated sites and facilities.

4. Construction: land development, highways and roads, and other heavy construction.

2.0 SUMMARY DISCUSSION

2.1 Introduction

Silviculture, agriculture, construction and mining have unique and distinguishing characteristics, and each activity has a somewhat unique set of nonpoint pollution problems. Similarities are perhaps more striking than differences, from the environmental point of view. In this section, the general features of nonpoint pollution from the four sources in the aggregate are presented, followed by discussions of methods for assessment of prediction of the extent of nonpoint pollution and an enumeration of sources and types of information and data available for use by the planner/engineer.

2.2 The Nature of Nonpoint Pollution from Agriculture, Silviculture, Mining, and Construction

The total land area in the 50 states of this country is 916 million hectares (2.264 billion acres). Land use data vary from year to year; on an average, one-half of this area is classified as "land in farms," and the remainder as "land not in farms."[1/] Urban America occupies about 25 million hectares[18/] (60 million acres), so almost 97% of the land area is rural in nature. Essentially all of the rural land is a source of nonpoint pollution, as is a substantial fraction of the urban land area. The present study is concerned with four sources of nonpoint pollution which are systematically influenced by commercial activities of man. These sources therefore generate pollutants in relation to the nature and extent of man's influence, and the pollution is amenable to control through modification of commercial activities.

Two of the four sources of concern in this study--agriculture and silviculture--together occupy 64% of the total land area in the United States. Construction and mining together occupy only about 0.6% of the total land area. The four nonpoint sources are, for purposes of this study, subdivided into a total of nine use categories, as shown in Table 2-1.

The area allocated to construction, 590,000 hectares (1 million acres), is that area brought under development annually for housing, highways, and like purposes.[6/] Commercial forest, 202 million hectares (500 million acres), is forest land which is producing or is capable of producing industrial wood, and has not been withdrawn from timber

TABLE 2-1

LAND USE DATA

	Millions of		Reference or Note
	Hectares	Acres	
Far land in Grass	218	540	16
Cropland, Plus Farmsteads and Roads[a]	167	412	16
Construction (Annual)	0.59	1.5	16
Commercial Forest Including Farm Woodlands and Forests	202	500	16
Annual Harvest of Forests (Growing Stock)	(4.45)	(11)	a,b/
Subsurface Mines	2.8	7	22
Surface Mines	1.2	3	22
Active Surface Mines	(0.12-0.16)	(0.3-0.4)	c/
Mineral Waste Storage	1.2	3	22
	592.79	1,466.5	

---

a/ Calculated from data presented in Tables 779 and 781, Agricultural Statistics, 1972, United States Department of Agriculture (Ref. 16).

b/ Commercial forest acreage includes acreage harvested annually.

c/ Area involved annually in surface mining, estimated from analyses of rates of growth in surface mining from 1920 to 1970 and predictions of growth through year 2000.[22]

utilization by statute or administrative regulation[16] (about 105 million hectares (260 million acres) of forest land is not available for production of industrial wood). Approximately 2% of the commercial timber inventory is harvested each year, which translates into an annual harvested area of 4-5 million hectares (10-12 million acres). The harvested forest acreage was calculated from data on timber inventories and timber removals presented in Agricultural Statistics, 1972.[14]

The acreage involved in subsurface mines (2.8 million hectares (7 million acres)) is only in part disturbed at the surface in a manner directly attributed to the mining activity. Much of this surface area is used for other purposes--parks, industry, cities, forests--particularly if the mines have been abandoned. Surface mining has to date affected 1,200,000 hectares (3 million acres) of land,[22] and an equal land area is dedicated to storage of mineral wastes from mining activities. Surface mining currently affects about 140,000 hectares (350,000 acres) of land annually (see Table 2-1).

Cropland, grassland, and commercial forest are on the basis of land area potentially large contributors of pollution. The remaining sources in Table 2-1, construction and mining, involve relatively small areas of land, and would appear on this basis to have less potential to degrade water quality. Generation of pollution from land under these various uses is governed chiefly by the manner of use, however. The pollutant load yielded by a particular class of land is the product of an appropriate pollution emission factor determined by land use practices, and the area dedicated to the particular use.

It is informative to consider agriculture, silviculture, construction and mining from the standpoint of total nationwide generation to water pollution. The planner/engineer is nearly always concerned with local or regional water quality, however, and thus requires local or regional emission factors for watersheds which are affected by some combination of construction, agriculture, silviculture, and mining.

Several classes of pollutants from agriculture, silviculture, mining, and construction have been identified as significant degraders of water quality. These are discussed, in summary fashion, below.

2.2.1 Sediment: Representative data for on-site erosion from several types of sources are shown in Table 2-2.

If one assumes that grassland and forest represent the "natural" state for cropland and construction land, the comparisons in Table 2-2 lead to the conclusion that tillage practices are responsible for 95-99%

TABLE 2-2

REPRESENTATIVE RATES OF EROSION FROM VARIOUS LAND USES

	Metric Tons/ sq km/year	Tons/ sq mi/year	Relative to Forest = 1	Reference
Forest	8.5	24	1	6
Grassland	85	240	10	6
Abandoned Surface Mines	850	2,400	100	
Cropland	1,700	4,800	200	6
Harvested Forest	4,250	12,000	500	13,1
Active Surface Mines	17,000	48,000	2,000	
Construction	17,000	48,000	2,000	6

of the erosion from cropland; and that construction activities result in 99.5% of the sediment eroded from construction sites.

An approximate relative ranking of the contributions of sediment (on-site), on a nationwide basis, from the seven types of nonpoint sources is presented in Table 2-3.

TABLE 2-3

RELATIVE EROSION FROM VARIOUS LAND USES: NATIONWIDE

Commercial Forests	1
Abandoned Surface Mines	< 1
Active Surface Mines	2
Construction	6
Harvested Forests	11
Grassland	11
Cropland	168

Cropland clearly is the major source of sediment. It has been credited with responsibility for 50% of the sediment delivered to streams and lakes, which totals about 1.8 billion metric tons (2 billion tons) annually (or half the on-site erosively generated sedimented production rate of 3.6 billion metric tons (4 billion tons) per year. Erosion from cropland varies widely in response to a number of variables: rainfall and rainfall intensity; type of crop; soil characteristics; topography; type of tillage; and conservation practices such as terracing and contour tillage. With good management, a particular operation can reduce erosion substantially from the rate which occurs when croplands are managed without concern for erosion.

The erosion attributed in Tables 2-2 and 2-3 to grassland is that which results from adequately managed grassland. Overgrazing, and the resultant loss of groundcover, can greatly increase the erodibility of grassland.

Construction and surface mining activities yield sediment at quite high rates. Each of these activities is a less significant source of sediment than cropland on a nationwide yield basis. However, both rates are quite high from the standpoint of creation of local problems such as plugging storm sewers and blanketing spawning areas with silt. Both types of activities have high sediment delivery ratios (fraction of on-site sediment delivered to water bodies) relative to cropland and other land uses.

Well-stocked, well-managed forest land can be remarkably resistant to erosion. Indeed, intense rainfall can be absorbed without runoff by a forest with good tree cover and a forest floor well covered with duff (decaying twigs, leaves, etc.). Forests devastated by wildfire and disease become highly susceptible to erosion. The harvest of trees from a forest creates a temporary condition which promotes erosion. Good silvicultural management practices can, as in agriculture, markedly minimize the adverse effects of timber harvesting.

Sediment is rated as the most significant of the pollutants from agriculture, silviculture and construction, and it also ranks high as a pollutant from surface mining.

2.2.2 Mineral pollutants: In some parts of the country minerals arising from nonpoint pollution sources present more serious water quality problems than does sediment. The affected areas are normally associated with mining activities. While the sphere of influence of the mineral pollution is more localized than that of sediment, it is a serious water quality problem in the localized regions where it occurs.

This section discusses three types of mineral pollutants: acid mine drainage, salinity, and heavy metals.

(a) Acid mine drainage: Acid mine drainage is a mixture of sulfuric acid and iron and aluminum salts which arises from the oxidation of pyritic materials associated with coal and mineral deposits. It is found in parts of Appalachia and in the western United States. Not all mining areas have mine drainage. Even in heavily mined areas of Appalachia, mine drainage has not been noted at many mining operations.

An accurate current assessment of the mine drainage problem is difficult, because: (1) abatement efforts are being implemented; (2) new areas of active mines are being worked; and (3) mined out areas are being shut down. In addition, the volume and composition of mine drainage depends greatly upon local physiographical conditions, i.e., geology, hydrology, and topography. Thus, it is virtually impossible to describe a "typical" acid mine drainage.

Mine drainage in the Appalachian Region of the United States has been the most completely characterized. In 1969, the Appalachian Regional Commission published a six-volume report detailing all aspects of the mine drainage problem in the Appalachia.2/

This report has served as the basis for planning mine drainage control and abatement projects in that region. At the time of the Appalachian Regional Commission's report, about 2 million kg of acidity (as calcium carbonate equivalent) was emitted daily in Appalachia. Since that time, the amount of acidity emitted as mine drainage has been reduced.

Mine drainage in Appalachia comes from three main sources: underground mines, surface mines, and spoil (gob) piles. The mines include active and inactive mines. The gob piles are mining refuse, discarded from coal processing operations, which contain pyritic materials. The contour strip-mines in Appalachia have often left mine spoil on the downslope of hills, and acidic discharges complicate the sediment problem from strip-mining in the area.

In the western United States, mine drainage is associated with hard rock minerals (copper, silver, gold, molybdenum, etc.), rather than coal. The problem is somewhat different than in Appalachia, since rainfall in the Rocky Mountain Region is quite variable. Indeed, in some of the arid parts of the West, mine drainage does not occur, simply because there is no water available for its formation.

Mine drainage in the West is less well characterized than it is in Appalachia. The U.S. Geological Survey, Water Resources Division, Colorado District, is presently conducting a study24/ on the "Effects of Mining on Surface Water Quality Exclusive of Uranium Mining in Colorado." This study will present data on the current status of mine drainage (and heavy metal) pollution in Colorado, and should serve as a basis for planning of mine drainage control and abatement efforts.

Acid mine drainage can be readily neutralized to form neutral salts. Thus, calcium sulfate salinity (the neutralized end product of sulfuric acid and limestone) in waters is commonly associated with neutralized mine drainage.

(b) Salinity: Saline water is common throughout many parts of the country, particularly in western United States groundwaters. Differentiation between salinity arising from man's activities and from natural phenomena is difficult. All natural waters contain salts of various types and in various concentrations. Some of the salinity is attributable to runoff from agricultural and forest land, some to neutralized mine drainage, and regions of intensive irrigation, to irrigation return flows. Irrigation return flow has been excluded from the scope of this study.

The salinity problem in the Colorado River Basin has been the subject of an in-depth study. Results of this study have been recently summarized,3/ and extensive field data are available in open file reports which can be reviewed in the offices of Region VIII, Environmental Protection Agency, Denver, Colorado.

The Colorado River Basin Study recognizes two basic causes of salinity in streams: salt loading and salt concentrating. Salt loading is associated with discharge of mineral salts into stream systems in municipal and industrial wastes, and in irrigation return flows. Natural sources such as springs, influent groundwater, and runoff are also major sources of salt loading. On the other hand, salt concentrating is associated with consumptive use of water. No mineral salts are added, but the concentration of salt increases as a result of water lost from the stream system.

As mentioned above, neutralized acid mine drainage is a source of saline pollution. Acid mine drainage can be neutralized by treatment processes typified by addition of lime in a water treatment plant or by natural processes (mine drainage passing through formations containing limestone or calcareous shale). For those cases where the acid mine drainage discharge is small and the stream receiving the drainage is large, the acid is often neutralized by the natural bicarbonate alkalinity in the receiving stream.

A major problem associated with neutralized acid mine drainage is the calcium and magnesium sulfate neutralization products. The calcium (or magnesium) sulfate contributes greatly to the hardness of the neutralized water. The hardness is of the "permanent" type, and the water usually requires additional treatment with soda ash in water to soften to acceptable levels.

Softening hard water with soda ash (or by ion exchange) does not reduce salinity. The softening process merely replaces calcium or magnesium sulfate with sodium sulfate. In parts of Pennsylvania, the principal sources of water supply is surface water contaminated with mine drainage. The high concentrations of sodium sulfate in the lime-neutralized, soda ash-softened water are a source of concern in these communities.8/

(c) Heavy metals: The third type of mineral pollution considered--heavy metals--is less well characterized than are mine drainage and salinity. The most readily identifiable heavy metal pollutant sources are associated with mining operations, particularly those in the western United States. Heavy metals in pesticides used in agriculture are potential pollutants. However, the heavy metal pollution potential of pesticides is less well defined than that associated with mining-related activities.

Acid mine drainage has the potential of leaching heavy metals from rock strata through which it passes. Most mine drainage contains iron, manganese, and aluminum, the aluminum arising from dissolution of clay materials. Manganese is present because it is a common impurity in pyrite. In the western United States, trace concentrations of the following heavy metals are often found: arsenic, antimony, cadmium, cobalt, copper, lead, mercury, nickel and zinc.

Arsenic arises in mine drainage through the oxidation of arsenopyrite, and iron-arsenic sulfide associated with some hard rock ores. Arsenopyrite undergoes the same types of reactions as does ordinary pyrite, thus creating an acid mine drainage containing arsenic.

A part of the heavy metal pollution potential in the western United States arises from sediment laid down in valleys from uncontrolled mineral processing operations. In many mineral processing operations in the West, mineral tailings were discarded into the nearest streams. The tailings often contained heavy metals. Although tailings impoundments (ponds) are now required, the sediment laid down in stream beds prior to control is a potential heavy metal source. For example, mercury has been found in groundwater associated with tailings discharge from the Homestake Mine (gold) in South Dakota.

Some heavy metals in western waters arise from natural sources. Arsenic not associated with mining14/ has been found in some Nevada water supplies in concentrations in excess of public health standards.

2.2.3 Nutrients: Nutrient elements, particularly nitrogen and phosphorus, are major nonpoint pollutants. These elements are abundant in nature, and it thus is difficult to deduce the specific origin of most of the nutrient elements present in this country's water supplies. Phosphorus is a pollutant of concern because of its role in eutrophication, and nitrogen likewise is involved in eutrophication processes. Ammonia, a reduced form of nitrogen, is toxic to aquatic life at low concentration. Oxidized nitrogen, chiefly nitrate, is present in most waters, and can be a direct threat to human health at higher concentrations.

In addition to naturally available nitrogen and phosphorus, the nutrient elements are derived from fertilizers and livestock wastes in large quantities.

Commercial fertilizer is currently consumed in the United States at a rate of about 37 million metric tons (41 million tons) per year.[16/] Total plant nutrients (nitrogen, phosphorus, and potassium) contained in the commercial fertilizer is about 15.5 million metric tons (17 million tons). The quantity of nitrogen in commercial fertilizer, about 7.3 million metric tons (8 million tons) per year, is about one-third of estimates[5/] of annual inputs to the soil compartment. The phosphorus content of commercial fertilizer (about 1.9 million metric tons, 2.1 million tons annually) is approximately 1.5 times the phosphorus content of livestock wastes. Livestock wastes and commercial fertilizer combined contain some 12 million metric tons of nitrogen per year (13 million tons), and 3 million metric tons of phosporus per year (3.3 million tons).

The quantities of nitrogen which escape to surface and groundwaters has been estimated[5/] to be 5.5 million metric tons (6 million tons) per year. More than half is presumed to be transported on sediment and the remainder by leaching. It has further been estimated that 10-15% of the nitrogen entering the system via fertilizers is lost to water.

Total phosphorus emissions[23/] from nonpoint sources have been estimated to be 0.73 million metric tons (0.8 million tons) per year, or about 25% of the phosphorus made available annually in the form of fertilizer and livestock wastes. Phosphate emissions are closely related to erosion, since phosphate sorbs strongly on soil and resists leaching. Nitrogen in both the reduced (ammonia) and oxidized (nitrate) state is water soluble, and nitrogen emissions occur, both to surface and groundwaters.

Nutrient emissions from various sources should be weighted to take into consideration the amounts of fertilizer and livestock waste added to the land, size of the land area treated, and the relative resistance of the land use to erosion. Approximately 75% of the commercial fertilizer and essentially all of the livestock wastes are concentrated on cropland and pasture/range land. As with emissions of sediment, cropland is a large single source of nutrient elements.

2.2.4 Pesticides: Pesticides are released directly into the environment in the course of their intended use. Unfortunately, the relationship between quantities of applied pesticide and the quantities which become a water pollutant are not well defined. Water pollution from pesticides is a function of the properties of a chemical, of its mode and rate of use, and of the care exercised in application.

Most pesticide chemicals are toxic to man and higher animals. They may also affect lower organisms, including organisms that are part of the vital natural biological waste degradation and/or oxygen production mechanisms. Persistent pesticides and/or pesticide metabolites and degradation products may accumulate in the environment, and some pesticides may biomagnify in ecosystems. The latter problem is of special concern in water quality management.

(a) Pesticides in agriculture: Chemical pesticides including insecticides, miticides, fungicides, herbicides, nematicides, rodenticides, plant growth regulators, desiccants, and others are used extensively in U.S. agriculture for the protection of crops and livestock from pests. The total quantity of pesticides used annually for this purpose is not known exactly. The U.S. Department of Agriculture17/ has estimated that farm uses of pesticides account for 55% of the total domestic use of pesticides. On this basis the department estimated pesticide use by farmers in 1966 and 1969 as follows:

	Active Ingredients Million kg (lb)	
	1966	1969
Insecticides	88.5 (195)	90.8 (200)
Herbicides	56.8 (125)	99.5 (175)
Fungicides	15.0 (33)	16.0 (35)
Total	160.3 (353)	186.3 (410)

The U.S. Department of Agriculture[19] recently published data on the estimated extent of chemical weed control in the United States in 1959, 1962, 1965, and 1968. According to this report, the herbicide-treated acreage increased from 21.5 million hectares (53 million acres) in 1959 to 60.7 million hectares (150 million acres) in 1968. The largest increases in treated acres were on land grown to corn, small grains, cotton, soybeans, and sorghum.

(b) Pesticides in silviculture: The U.S. Department of Agriculture[17] reports that forest insects and diseases are responsible for losses in the U.S. each year that far exceed the losses from forest fires. Current annual forest mortality due to insects and diseases combined is estimated at about 68 million m^3 (2.4 billion cu ft). It is estimated that insects and diseases cause an additional, equal volume, of growth loss. Forest losses would be about 28 million m^3 (1.0 billion cu ft) higher if no pest control activities were carried out. The use of chemical insecticides and fungicides is credited with about two-thirds of this saving.

Major pest control operations in 1969 by federal, state and private interests combined are summarized in a report by the USDA's Forest Service.[10] Over 1.25 million trees were treated for insect pests such as the southern pine beetle and the white pine weevil, and 9,660 hectares (23,868 acres) were treated for the spruce budworm.

The U.S. Department of Agriculture[17] reports that in 1970, about 310,000 lb of insecticides and fumigants were used by the Forest Service for insect control. Pesticides used included ethylenedibromide, 107,000 kg (235,000 lb); fenitrothion, 23,000 kg (51,000 lb); carbaryl, 6,350 kg (14,000 lb); and smaller quantities of malathion, benzene hexachloride (BHC), and lindane. Two forest pests that accounted for a major part of the use of these chemical insecticides were the gypsy moth and spruce budworm.

The U.S. Forest Service has made a concerted effort in recent years to move away from the use of persistent insectides, toward increased reliance on cultural, biological and integrated control methods and the use of nonpersistent, more specific chemicals.[10] The service has made no aerial applications of DDT since 1967. Its use of BHC decreased from 3,990 kg (8,790 lb) in 1966, to 26 kg (57 lb) in 1970. The total use of pesticides in these programs has been reduced from about 614,300 kg (1,353,000 lb) in 1965, to about 141,000 kg (310,000 lb) in 1970.

Herbicides are used in silviculture more frequently than insecticides and fungicides, but still only a very small portion of forest land is treated with herbicides in any given year.[1] Herbicides are used mostly to control undesirable plant species and weeds in new plantings. Herbicides have also helped to prevent forest fires by reducing growth of combustible plant materials on fire breaks and along forest roads.

The U.S. Forest Service sprayed 108,702 hectares (268,666 acres) for the control of noxious weeds or undesirable woody vegetation in 1969. This included about 33,600 hectares (83,000 acres) treated with 2,4,5-T, alone or in a mixture with 2,4-D.[10]

The USDA[19] estimated that 187,000 hectares (463,000 acres) of forest plantings (presumably including publicly as well as privately owned lands) were treated with chemical herbicides in 1968, an increase from an estimated 111,000 hectares (274,000 acres) treated in 1962. Twenty-two states contributed data to this report. Of these, 19 reported an upward trend in herbicide usage in forest plantings; one state reported a stationary trend, two states a downward trend.

(c) Pesticides in construction: Pesticides may become environmental pollutants as a result of construction activities basically in two different ways:

1. Pesticides may be used during the construction work to protect the building, highway, etc., from attack by pests such as insects, weeds, and diseases.

2. Construction work may involve movement of soil containing pesticide residues from prior use of pesticides on the site. Increased soil erosion usually associated with such earth movements may mobilize such pesticide residues and increase their rate of passive transport into waterways.

The most important use of chemical insecticides in construction activities is the protection of wooden structures and structural elements from attack by subterranean termites. Persistent chlorinated hydrocarbon insecticides including chlordane, aldrin, dieldrin, and heptachlor are the insecticides primarily used for control of, or protection against, subterranean termites. These insecticides provide 18 to 20 years protection in most instances. It is generally agreed that there is very little likelihood of environmental contamination from the proper use of persistent insecticides against termites.

Herbicides are sometimes used in construction projects such as paving of parking lots, driveways, secondary or county roads, or in similar situations where a relatively thin layer of concrete, asphalt, blacktop, or other material is laid down. The herbicide(s) are applied to the soil surface to prevent sturdy weeds from growing through the pavement. Again, this type of pesticide use entails very little risk of environmental contamination because the method of application prevents pesticide transport away from the site of application.

(d) Pesticides in mining: The only significant use of pesticides in connection with active mining operations consist of termite protection. Some herbicides may be used during land reclamation operations.

2.2.5 Biodegradable pollutants: Agricultural and silvicultural activities generate tremendous quantities of natural organic waste materials which are potential nonpoint pollutants. Moreover, all four sources--agriculture, silviculture, construction, and mining--distribute synthetic or foreign organic substances in the environment from which they have the potential to migrate into surface and groundwater. The major sources of organic wastes are livestock wastes; crop debris; forest litter, including annual leaf fall; and waste petroleum products (lubricating oils and greases, waste crankcase oil, and pesticide solvents or dispersants). Other less significant sources are cleaning solvents, waste paints and degraded surface coatings, waste materials from building and construction, and innumerable rural waste items.

That this source of potential pollution is not insigifnicant is shown by the fact that animal wastes amount to about 1.8 billion metric tons (2 billion tons) per year,[21] or nearly 2 metric tons/hectare (1 ton per acre) if distributed uniformly throughout the United States. This waste is restricted to approximately one-half the total land area, and localized areas can be highly loaded with animal wastes. Crop debris can be generated at rates of several metric tons per hectare.

The so-called "natural" organic wastes are, in well managed agricultural and silviculture operations, returned to the land and recycled by physical and biological degradation. The foreign or synthetic organic substances usually are dispersed fairly uniformly on land, where they in time are also degraded. Certain of these substances may be difficult to degrade, and will accumulate in the rural environment. The PCB (polychlorinated biphenyl) class of refractory organic materials exemplifies the latter problem. In this case a substance not a normal part of agricultural, etc., operations has become a very nearly permanent part of the environment, and is transmitted within the environment by nonpoint transport schemes.

On an overall basis, however, the biodegradable material load is accommodated fairly well on the land. A certain fraction, nevertheless, finds its way into the water resources. There it can be a physical nuisance and a physical obstruction to aquatic processes, by blanketing spawning beds or interfering with light and energy transmission. The most serious effect is biochemical, for microbial degradation of pollutant organic loads interferes with usual aquatic biological processes, and may result in depletion of dissolved oxygen to a level inadequate for aquatic animal life.

A majority of the organic waste material deposited in streams is transported thereto by erosion and runoff. For this reason, organic pollution is most severe where organic-laden surface covering is subjected to extreme erosive conditions. Tree harvesting from forests exposes forest litter to erosive forces, and the litter is an important source of organic pollution. Similarly, landspreading of livestock wastes will, if improperly carried out, yield a condition in which the wastes are highly susceptible to transport to water bodies via surface runoff.

2.2.6 Thermal pollution: Thermal pollution from solar radiation is a nonpoint problem in silviculture. Destruction of shade cover over forest-based streams can result in several degree rise in temperature compared to a shaded stream.[4] The change in temperature is often sufficient to cause considerable alterations of the aquatic ecosystems. The nature and extent of thermal pollution are well documented, and methods for analysis at the planning level are available.

2.2.7 Radioactivity: Traces of radioactive nonpoint pollutants are generated by-products of certain mining operations, and additionally are a by-product of fossil-fuel production and combustion. The radioactive mineral mining industry is, of course, a source of nonpoint radiation, though this industry strives to handle both products and by-products a [illegible] point" materials. The environment is being extensively monitored for radioactivity. Levels of radioactivity in aquatic systems are routinely below levels judged to be hazardous.

2.2.8 Microbial pollution: Pollution of streams, reservoirs, and groundwater by disease transmitting organisms is a problem which is not well characterized. The discharge of pathogens is associated most closely with livestock production. The extent of pathogen-containing discharges into surface waters is poorly documented. Pathogen contents of groundwater are minimal from nonpoint sources, particularly if the livestock operation is well managed. Nevertheless, microbial pollution is a continuing area of concern.

2.3 Models for Predicting Nonpoint Pollution

Prediction methods for nonpoint pollution can vary from very simple rules of thumb to very complicated computer procedures. The planner or engineer concerned with nonpoint pollution needs to have better tools than general rules of thumb, but less complicated than sophisticated models which involve the use of electronic computers. Existing prediction methods tend to be over-general, since they describe an average system in which pollutants are generated and transported. The real system is often significantly different from the average, and in most cases can best be described as the summation of several subsystems, each subsystem having been evaluated in terms reflecting its uniqueness.

Evaluation of the subsystems is usually based upon data of many types obtained from several kinds of samplings. The data obtained from a specific sample reflect conditions at a specific point in time and space, i.e., the time when the sample was taken at the sampling station. Thus, the planner/engineer needs to assess the data obtained from a particular sample in relationship to a base line established by many observations and analyses collected over a long time period.

This section describes criteria which are needed for better prediction models; a method for presenting base-line information, and an example in which prediction model criteria are applied to sediment production at a construction site.

2.3.1 Criteria for prediction models: The planner/engineer dealing with nonpoint pollution seeks three pieces of information:

1. What pollutants have been generated and dispersed;

2. How much pollutant has been generated; and

3. Do the data deviate significantly from the base line?

What pollutants are generated and dispersed within a region is usually determined by the types of activities which are occurring within the region. The pollutant sources, both point and nonpoint, are usually well-known and recognized. The nonpoint pollutants generated from agriculture, silviculture, mining, and construction are described in subsequent sections of this report.

How much pollutant is generated can be addressed by several procedures. For the case of sediment pollution, the Universal Soil Loss Equation[25] and the Musgrave Equation[11] for erosion losses have found widespread utilization. Specifics of the two soil loss equations are presented in Section 3.0. For the case of chemical pollutants, knowledge of flows and pollutant concentrations is required to establish quantities emitted.

The question of whether a set of analytical data deviate significantly from base-line data is of crucial importance. Data obtained from an individual sample reflect conditions at a particular point in time and space. If the data are significantly different from similar data taken at the same spatial point but at different times, then it can be concluded that some event has occurred in the vicinity of the sampling station which has affected the sample. Such a conclusion assumes, of course, that the analyses have been properly performed and that the sample is representative.

Sufficient data are available in many parts of the country to establish base-line data for many pollutants. These data need to be analyzed by statistical methods so that pollutant base-line data can be expressed by rules of thumb, equations, and nomographs. Such statistical analyses have provided the basis for the soil loss equations,[11,25] equations for predicting thermal pollution,[4] and for preparation of nomographs which describe several specific pollutional situations.

2.3.2 The Hydrograph: A method for presenting base-line information: The base-line data including the nomographs, predictive equations, and rules of thumb, provide a frame of reference with which subsequent data obtained for various pollutants can be compared. Base-line information can arise from many sources besides chemical analysis performed to describe water quality. For example, the discharge of runoff as a function of time is often summarized in a hydrograph. The hydrograph can be used as the basis for developing base-line data for surface runoff, the common method for transporting pollutants from land into surface waters.

A hypothetical hydrograph is presented in Figure 2-1. The shape of the hydrograph will depend upon several factors: rainfall amount, rainfall duration, rainfall intensity, and soil classification. The amount of discharge is determined by the area and topography of the drainage basin. In regions of similar topography, a large drainage area will produce more runoff than a small drainage area. On the other hand, a small compact drainage area with steep slopes would produce more runoff than a larger, more elongated watershed having gentle slopes.

The shape of the hydrograph will vary with respect to rainfall duration and intensity in the following way. A storm of heavy rainfall over a short duration will peak towards the left side of the hydrograph. A gentle rain over a long duration will peak towards the right and tail off more slowly. Effects of rainfall intensity and rainfall duration on the hydrograph are shown in Figure 2-2. Similarly, a rainstorm in an area of highly permeable soil will show a long time lag between the time the storm begins and the time that runoff peaks. A similar event in an area with tight clayey soil will be shifted to the left and peak at a much earlier time.

The hydrograph consists of three basic segments:

1. The approach segment, AB, reflecting the time lag between commencement of rainfall and the commencement of runoff;

2. The rising segment, BD, reflecting increased runoff until it peaks at point D; and

3. The recession flow, DF, reflecting decreased runoff after rainfall has ceased.

The inflection points in the rising and receding curves, C and E, respectively, define the crest of peak segment of the hydrograph, CDE. Point F represents the return to normal base flow.

The construction of hydrographs is a straightforward procedure, although somewhat tedious. Information required and methods for constructing hydrographs have been presented by Ogrosky and Mockus.12/ These authors also present methods for interpreting the hydrograph, and interpolating standard hydrographs (called unit hydrographs) to specific runoff events. A unit hydrograph describing a particular drainage basin may be used for similar basins by introducing other values into the parametric equations from which the unit hydrograph is constructed.

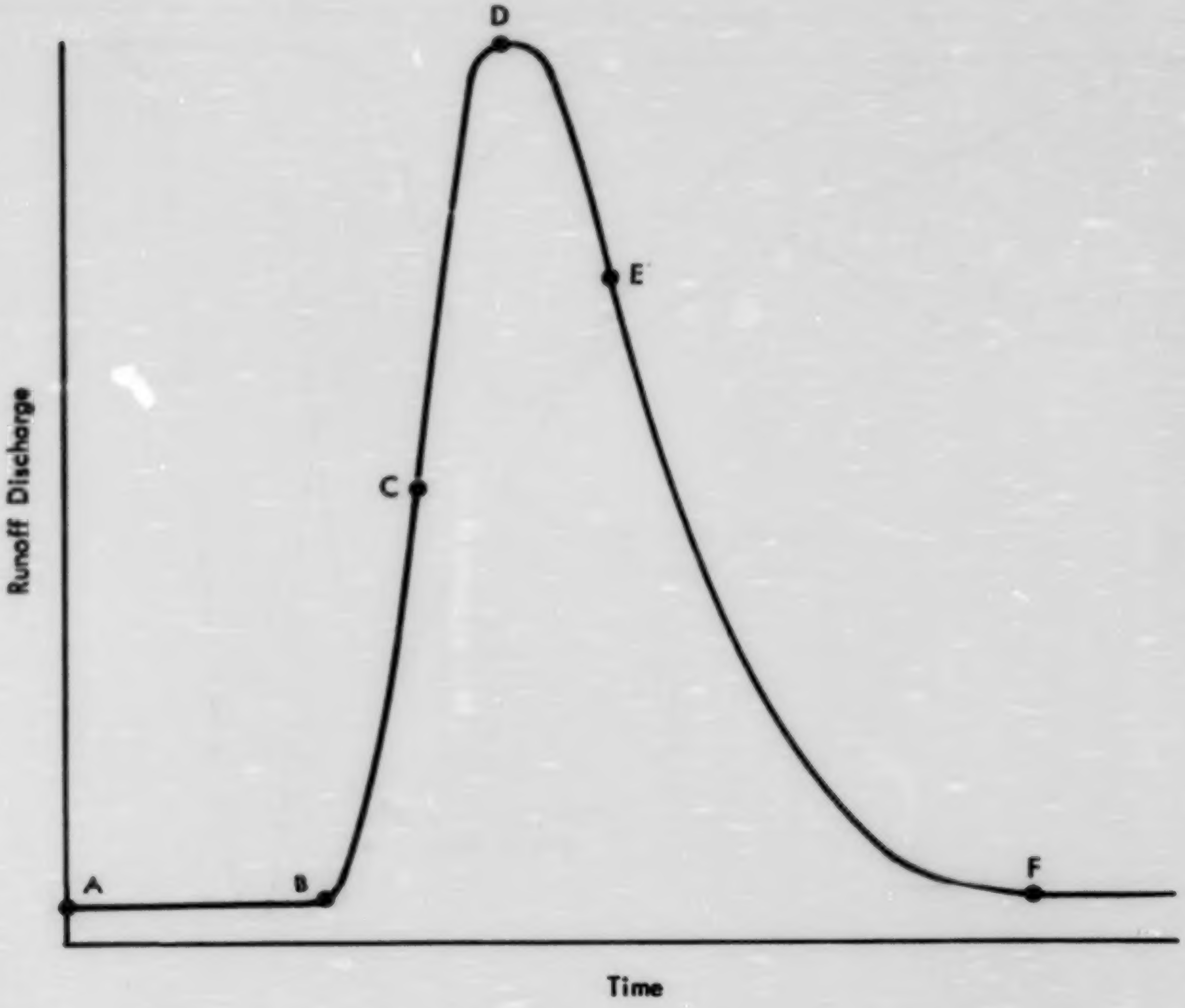

Figure 2-1 - A Hypothetical Hydrograph

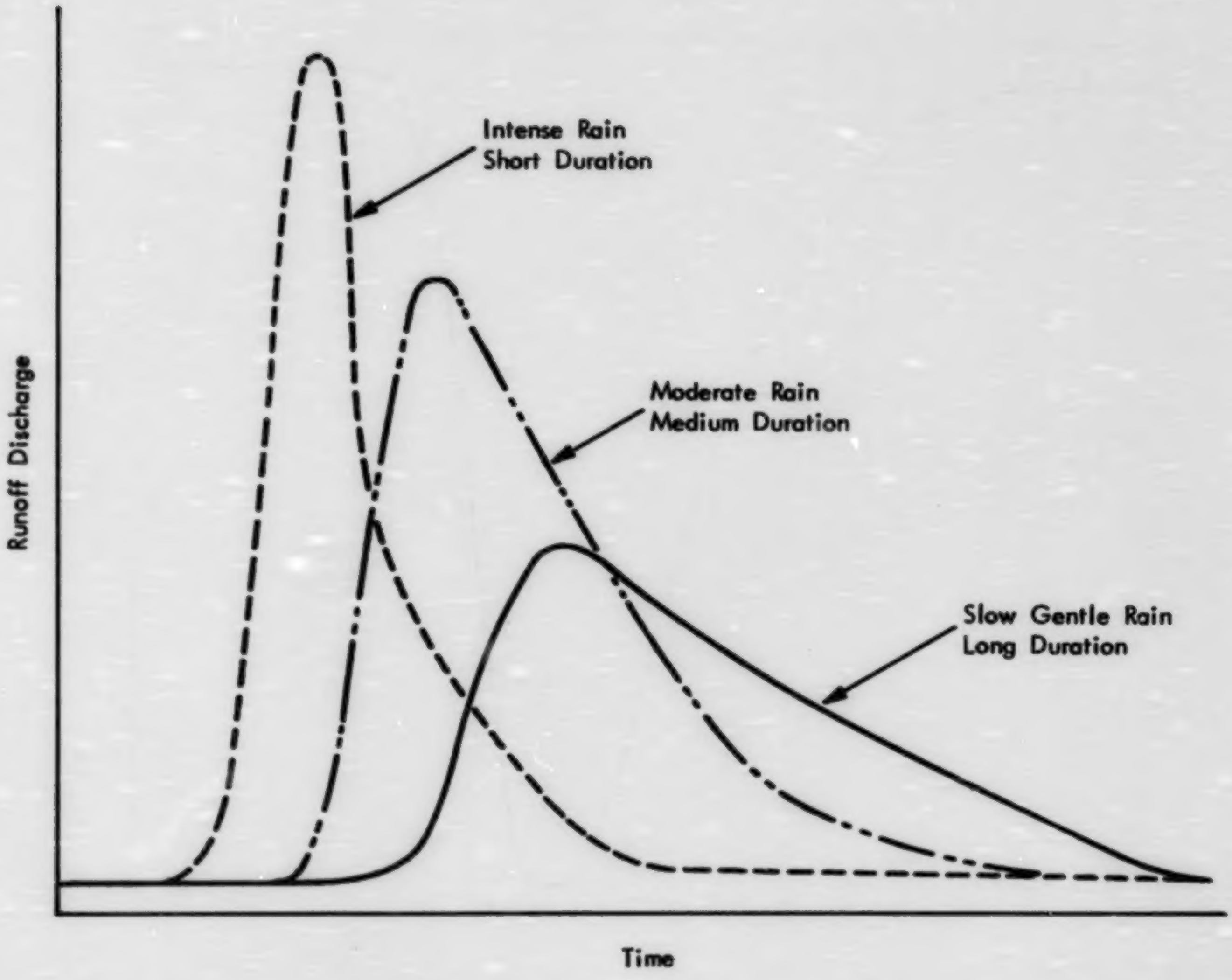

Figure 2-2 - Hypothetical Hydrographs Showing Effects of Various Storm Types

Data inputs needed for constructing hydrographs include: drainage basin area, duration of rainfall, amount of rainfall, excess rainfall (above that absorbed by the soil), infiltration rates, and soil types. Since the hydrograph construction is straightforward, computer techniques for plotting the hydrograph are certainly applicable.

2.3.2 Application of a hydrographic data base to sediment pollution: The hydrograph is designed for use with runoff discharge, and does not specifically deal with pollutants that may be contained in the runoff. Since material in runoff is the prime source of nonpoint pollution, the planner/engineer needs to know how much and what kinds of pollutants can be expected in the runoff.

The principles outlined above have been applied to the specific problem of sediment in runoff at a highway construction site by Swerdon and Kountz.[15] In this study, information from hydrographic analysis provided the "volume" factor for determining sediment concentrations in runoff. The "mass" factor in the concentration was supplied by the application of the soil loss equation over a 24-hr storm period yielding 4.6 cm (1.8 in.) of rain. This storm was typical of one in the area during the time of construction. By a straightforward manipulation of predicted sediment yields during the standard storm, and of predicted volume and flow distribution of runoff, it was possible to determine accurately catch basin design parameters for retaining sediment during the construction of an interstate highway segment in Pennsylvania.

The approach of Swerdon and Kountz yielded a sediment concentration curve as a function of time. The shape of this curve was very similar to that of the hydrograph shown in Figure 2-1. The only practical difference between the sediment concentration curve and the hydrograph was the difference in units along the Y-axis of the plot.

The sediment concentration levels were determined by applying the soil loss equation to several subareas within the main drainage area of concern. The soil losses for a 24-hr 4.6-cm rainfall were estimated for each subarea. These losses were then totaled and divided by the volume of runoff. The summation of data arising from the application of the soil loss equation to a number of subareas in the drainage basin is not a formidable problem. Methods for quickly summing over the subareas have been presented by Swerdon and Kountz. These summation principles are applicable to any source of nonpoint pollutants to obtain usable pollutant production estimates.

The sediment concentration-time curves generated by Swerdon and Kountz are illustrative of a potentially useful approach for the planner concerned with nonpoint pollution. For example, several plots of sediment concentration as functions of storm duration will show results expected from several storm intensities, indicate how much sediment can be expected during a variety of rainfall events, when the sediment loads would peak, and how long a stream would exhibit sediment concentrations above those found in base flow.

The resulting family of curves contain a useful description of base-line conditions. They will provide a ready means to determine when an unusual polluting condition exists. And they will provide the basis for predicting response to control measures and to disturbances in the watershed.

The planner in each region will necessarily have to consider the parametric values and basic characteristics which describe his watershed (or other area of interest), develop this information into descriptive models, and continue the process of evaluation through to development of predictive tools which suit his needs. Much useful information is available and accessible to the planner, and is very nearly adequate for describing base-line characteristics. Details of procedures and techniques for translating this information into useful descriptive and predictive models are in some instances adequately developed (e.g., for prediction of erosion specific aspects of mine drainage, and thermal effects on streams), and in other instances (e.g., pesticides, nutrients, and heavy metals) inadequately developed.

2.4 Sources of Information Relevant to Assessment of Nonpoint Pollution

Information and data of considerable variety are needed to evaluate nonpoint pollution problems and develop plans for their rectification. Water quality data for the region of interest are a necessity. Other needed information includes soil and geologic data, climatological data, topographic information, statistics on land use and livestock production, and statistics on the use of fertilizers and pesticides. Sources of information are listed in Table 2-4.

The following federal agencies have aerial photographs for many parts of the United States: Department of the Interior--Geological Survey, Topographic Division; Department of Agriculture--Agricultural Stabilization and Conservation Service, Soil Conservation Service, and Forest Service; Department of Commerce--National Ocean Survey; Department of the Air Force, National Aeronautics and Space Administration. Also, various state agencies and commercial aerial survey and mapping firms are sources of aerial maps and photographs.

TABLE 2-4

PUBLIC AGENCIES AS SOURCES OF DATA FOR IDENTIFYING AND EVALUATING NONPOINT SOURCE POLLUTION

Data Category	Data Source	Format
Water Quality	EPA	STORET
	USGS	"Water Resources Data"
	OWDC (USGS)	"Catalog of Information on Water Data: Index to Water Quality Section"
	WRD (USGS)	"National Reference List of Water Quality Stations"
	Bureau of Reclamation	
	Bureau of Mines	
	Forest Service	
	Bureau of Land Management	
	State Health Departments, Pollution Control Agencies, Game and Fish Commissions, Etc.	
Sedimentation	USGS	"Water Resources Data"

TABLE 2-4 (Continued)

Data Category	Data Source	Format
Sedimentation (Concluded)	SCS, ARS, Corps of Engineers, Bureau of Reclamation	Sedimentation Reports
Stream Flow	EPA	STORET
	USGS	"Water Resources Data"
	OWDC (USGS)	"Catalog of Information on Water Data: Index to Surface Water Section"
	Bureau of Reclamation	
	State Governments	
Climatological	Weather Bureau	"Climatological Data"
		"Rainfall Frequency Atlas of the U.S."
		Hydrologic Bulletins and Technical Papers
		Cooperative Study Reports
	Bureau of Reclamation	Cooperative Study Reports
	Forest Service and State Foresters	Fire-Weather Reports
	SCS, ARS, Weather Bureau	Rainfall-Erosivity Index

TABLE 2-4 (Continued)

Data Category	Data Source	Format
Topographic	SCS	"Conservation Needs Inventory"
	USGS	Topographic Maps
	National Park Service	Topographic Maps
	Forest Service	Topographic Maps
	State Geological Surveys	Geologic Maps
Geological and Soil Characteristics	SCS	"Conservation Needs Inventory"
	SCS, Forest Service	County Soil Survey Reports
	Bureau of Reclamation	Land Classification Reports
	USGS, State Geological Surveys	Geologic Maps and Reports
	State and County Highway Departments	Subsurface Soil Data
Land Use	SCS	"Conservation Needs Inventory"
	Bureau of Census	"Census of Agriculture"
	Forest Service	Forest Survey Reports

TABLE 2-4 (Continued)

Data Category	Data Source	Format
Land Use (Concluded)	Forest Service, SCS	Range Survey Reports
	Forest Service, State Foresters	Cutting Records
	U.S. Bureau of Mines	"Minerals Yearbook"
	State Agricultural Departments	State Cropland and Livestock Reports
	State and Regional Planning Agencies	
	State Department of Mineral Resources	
	State Geological Survey	
Livestock	Bureau of Census	"Census of Agriculture"
	USDA	"Agricultural Statistics"
	State Agricultural Departments	State Cropland and Livestock Reports
Fertilizer Use	USDA	"Agricultural Statistics"
	Bureau of Census	"Census of Agriculture"
	State Agricultural Departments	Fertilizer Tonnage Reports
Planimetric Maps	Bureau of Land Management	Plots of Public Land Surveys

TABLE 2-4 (Concluded)

Data Category	Data Source	Format
Planimetric Maps (Concluded)	Forest Service	
	County Surveyor or County Engineer	County Maps
	Bureau of Reclamation	Federal Reclamation Project Maps

Abbreviation list:
ARS - Agricultural Research Service (Department of Agriculture).
EPA - Environmental Protection Agency
OWDC - Office of Water Data Coordination (Geological Survey, Department of Interior)
SCS - Soil Conservation Service (Department of Agriculture)
USDA - U.S. Department of Agriculture
USGS - U.S. Geological Survey (Department of Interior)
WRD - Water Resources Division (U.S. Geological Survey)

The following Federal and state agencies have basin and project reports and special reports: Department of the Army--Corps of Engineers; Department of the Interior--Bureau of Land Management, Bureau of Reclamation, Bureau of Mines, Fish and Wildlife Service, and National Park Service ; Environmental Protection Agency; Department of Agriculture--Forest Service and Soil Conservation Service; state departments of water resources, public-works power authorities, and planning commissions.

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3.0 AGRICULTURE

3.1 Introduction

The impact of agriculture on the nation's water resources is significant. Farmland in grass, pasture, and cropland plus farmsteads and roads total over 385 million hectares (950 million acres) of land area in the United States, and is scattered across the face of the land, intimately connecting with nearly all of the major water sources. Cropland represents about 157 million hectares (387 million acres) of this farmland (see Table 2-1).

The major uses of water include industrial use, irrigation, public water supplies, navigation, recreation, and rural domestic uses. The quantity of water used for irrigation ranks second only to that for industrial use. Of the estimated 339 billion gallons of water consumed daily in the United States more than 35% is used for irrigation.[98] The impact of the use of water for irrigation is limited mostly to the 17 western states where about 14 million hectares (35 million acres) of the total 16 million hectares (39 million acres) of irrigated land are situated.

The trend in agriculture is to employ modern technologies at ever increasing levels of complexity involving the use of fertilizers, pesticides, irrigation systems, and confined animal feedlots. A consequence of this trend will be the increased potential for water pollution both in the surface water and in the groundwater. Protecting water quality will become a major concern for agriculture.

3.2 Sources of Pollution from Agriculture

The pollutants resulting from agricultural discharges include sediments, salt loads, nutrients, pesticides, organic loads, and pathogens. Sediment resulting from soil erosion is regarded as the largest pollutant that affects water quality. Agricultural lands, particularly cropland, are large contributers of sediment. Holeman[94] estimated the total erosion rate per year for the contiguous United States to be over 3.6 billion metric tons (4 billion tons), of which about 1.8 billion metric tons (2 billion tons) washes into streams and 0.9 billion metric tons (1 billion ton) reaches tide waters. The national conservation needs inventory of the Soil Conservation Service estimated in 1971 that the total sediment yield from cropland per year was more than 0.9 billion metric ton (1 billion ton). Thus, cropland is responsible for about 50% of the total sediment yield in inland waterways. Only a fourth of the total yield travels to the ocean. Sediment also carries with it significant quantities of plant nutrients, pesticides, organic and inorganic matter, pathogens, and other water pollutants.

About 1.8 billion metric tons (2 billion tons) of livestock wastes are produced annually in the United States.[107] Of this quantity, the liquid wastes are estimated to be over 360 million metric tons (400 million tons). As much as 50% of these wastes may be produced in feedlots. While most of these waste materials are confined and eventually spread on farm acreage, the runoff and seepage from this source poses a significant pollution hazard. Conservation treatment of the spreading area eliminates or significantly reduces runoff and the pollution hazard.

Commercial fertilizers consumed during 1972 amount to about 37 million metric tons (41 million tons) in the United States. These fertilizers contain roughly 20% nitrogen, 5.2% phosphorus, and 8.8% potassium. Farmers use about 75% of the fertilizer consumed in the United States. The composition of plant nutrients in commercial fertilizers applied in different states varies considerably. For example, in Nebraska, the composition of commercial fertilizers consumed during 1970 averaged about 40% nitrogen, 5% phosphorus, and 3% potassium. For Iowa, these values were approximately 27% nitrogen, 7% phosphorus, and 11% potassium.[98]

Some of these nutrients are transported, together with naturally occurring nutrient elements, to surface and groundwaters.

Irrigated agriculture involves leaching and transport of dissolved minerals in soils, and flushing the unwanted salts from the soil. About 60% of irrigation water is lost by evapotranspiration, while the remainder is returned by surface runoff and subsurface flow to surface waters and to groundwater storage. The return flows carry large quantities of minerals and degrade the water quality of the receiving streams.

Pesticides are designed to be lethal to target organisms, and many are toxic to nontarget organisms. Four major categories are important in agriculture: insecticides, fungicides, herbicides, and rodenticides. According to Pimentel, of nearly 454 million kilograms (1 billion pounds) of pesticides applied in the United States during 1970, about 70% was for farm use and the remaining 30% for public and governmental use.[79] It is anticipated that the use of pesticides will increase tenfold within the next 20 years.

The threat from pesticides is primarily due to their persistence in the aquatic environment, where fish and other food chain organisms accumulate pesticides and their metabolites or degradation products.

This phenomenon of biological magnification appears to be especially significant with the fat-soluble pesticides.

Organic loads from agricultural activities include rural wastewaters, animal wastes, crop residues, and food processing wastes. When these substances are carried to a water body, they exert a high biochemical oxygen demand (BOD).

Agriculture wastes are a source of pathogens. Diseases may be transmitted through soil, water, or air when these wastes come in contact with plants and animals. Agricultural losses caused by infectious agents of livestock and poultry have been substantial. Wadleigh has summarized the cases of diseases transmitted by infectious agents and allergens affecting plants and animals from agricultural wastes.107/

3.3 Pollutant Transport

There are three modes of transport of pollutants from agricultural sources to water: (1) by runoff to surface water; (2) by infiltration and percolation to subsurface water; and (3) by wind to surface waters.

The pollutant may be dissolved and carried by water, or may be adsorbed and transported with sediment. When transported in an aqueous phase, hydrological factors describing the motion of the water from the source to the point of discharge in a stream or a lake must be known to predict the extent of pollution. In the sediment phase, the rates of transport of suspended sediment, as well as the bedload, must be considered. In a watershed, interactions of several sources which contribute to a common sink are complex and difficult to predict.

The mechanisms of nutrient transport and deposition in waterways have been investigated under several local conditions and are basically known. However, a knowledge of these mechanisms is not adequate to determine the extent of nutrient losses from individual sources such as fertilizers and livestock wastes, or how these losses may be affected by soil and land characteristics, and management systems.

3.3.1 Water: Runoff from croplands, animal feedlots, and pasture and rangelands is a major mode of transport of pollutants that enter a water resource. Subsurface drainage may also carry significant quantities of pollutants that are dissolved in water. Surface water carries suspended sediment in large quantities. Many pollutants such as phosphates and pesticides are tightly bound to sediments and are thereby transported to river and reservoir bottom muds. Though phosphorus is held strongly by bottom sediments, the net release of even a small fraction to the surface water can adversely affect water quality.

Groundwater pollution stems mainly from increased nitrate concentrations from percolation and infiltration. Leachates from feedlots have been shown to contribute to nitrates in the groundwater. Groundwater salinity has been increased through crop irrigation and return to the water table. Increased irrigation in the Pacific coastal area by withdrawing groundwater has created pressure differences in the saltwater-freshwater interface, resulting in saltwater intrusion.

3.3.2 Wind: The process of wind erosion consists of particle detachment, transport, and deposition. The critical or threshold conditions under which soil movement is initiated have been the subject of intensive wind-tunnel and other laboratory experiments. Chepil[6] and Chepil and Milne[7] found that the most significant factor influencing the threshold velocity of any soil is the size of the soil grains. This critical velocity is a minimum for particles between 0.1 and 0.15 mm in diameter.

The movement of soil by wind action takes place through the following mechanisms: (1) saltation; (2) surface creep; and (3) atmospheric suspension. Saltation denotes the bouncing movement of particles within a layer close to the ground surface. Surface creep is induced by the impact of particles descending from saltation. Atmospheric suspension is the process by which fine soil particles are lifted into the turbulent air stream and may be carried large distances.

The proportion of soil moved by wind varies widely for different soils. Coarsely granulated soils erode by saltation and surface creep; finely pulverized soils, by saltation and atmospheric suspension.[87] Ninety percent of the soil moved by wind is through saltation or surface creep processes. The balance is through atmospheric suspension, which is a source of water pollution by wind action.

The three major factors controlling wind erosion are the characteristics of the wind, the soil, and the soil surface. The erodibility of soil by wind is primarily determined by soil moisture, soil texture, structure, and stability. According to Chepil[6,47] a simple but effective index of soil erodibility is the proportion of soil fractions greater than about 1 mm in diameter, as determined by dry sieving. Soil particles with diameters less than about 1 mm are generally considered erodible, while soils resistant to wind erosion contain at least two-thirds by weight of fractions greater than 1 mm.

The use of soil erodibility index for wind erosion appears to be limited. The extent of soil losses due to wind erosion has not been systematically analyzed. Data indicating the quantity of wind-borne sediment deposited in a water body are not currently available.

3.4 Extent of Pollution from Agriculture

The significance of pollution from agricultural sources in the protection of our water resources is the subject of several conferences, symposia, and reports in recent times.[1,9-11,23,26-29,33,42,53,55,70,84,93,107,115] In addition, several papers describe the general and specific aspects of agricultural waste contributions to environmental pollution.[3,4,14,15,18,20,22,24,25,30,31,39,43,44,61-64,66,69,72,76,88-90,92,96,101-105,108-112] A detailed discussion is not attempted in this report as the subject has been well documented in the published literature. A brief overview will be presented in the following sections.

3.4.1 **Cropland**: Croplands rank as the largest producer of sediment. Sediment is considered by far the most important water pollutant from agriculture. About 1.8 billion metric tons (2 billion tons) of sediment are washed into streams in the U.S. each year.[48]

Wadleigh[107] estimated the average analysis of sediment to be 0.1% nitrogen, 0.08% phosphorus (P), and 1.25% potassium (K). Thus, the loss of nitrogen and phosphorus to our waterways would be approximately 1 kg of N per metric ton of sediment (2 lb of N per ton), and 0.8 kg of P per metric ton of sediment (1.6 lb of P per ton). Erosion is thus an important factor in loss of nutrients to surface waters. Many substances which are either present on land as plant residues, are introduced on cropland by man, or are produced as wastes by agricultural activities, have significant effects when introduced into receiving waters. Of these, the most publicized materials include pesticides and plant nutrients. Pesticides have been receiving much attention due to their adverse ecological effects on food chain organisms, especially on aquatic communities. The ban of persistent chemicals such as DDT highlights the degree of concern in this area. However, the movement of pesticide residues from cropland into waterways is a complex process, and depends on many factors such as the physical and chemical properties of the toxicant, the formulation, the rate and type of application, the crop to which it was applied, tillage practices, topography of the field, topography of the area between the application site and waterways, distance between application site and waterways, weather conditions, and amount and velocity of rainfall following application. Limited data are available to demonstrate quantitatively how these factors will affect the relationships between quantities of pesticide input and pesticide residues in rivers, lakes and oceans. Edwards[19] has summarized typical amounts of DDT in aquatic and in terrestrial food webs (see Figure 3-1).

Most pesticide residues are found in the uppermost layer of tilled cropland soils, i.e., in the stratum that becomes a "soil loss" in the process of sheet erosion. Consequently, pesticide soil residue data may be correlated with the sediment load of the waterways to determine the extent of pesticide losses to surface waters.

Less dramatic, but equally alarming is the problem of lake eutrophication, attributed in part to the application of fertilizers on farmland. Of special concern are the major nutrients, phosphorus and nitrogen. Nitrogen can find its way into groundwater or surface water generally as a dissolved salt. The evidence suggests that nitrogen may be taken up at the root zone, escape to receiving ground or surface waters, or evolve to the atmosphere through denitrification processes. The nitrogen percolating into groundwater accumulates in aquifers and contributes to potential problems of nitrate toxicity.

Estimates of the loss of nitrogen from agriculture sources vary considerably. For example, in Upper Klamath Lake, Oregon, 20% of the nitrogen was estimated to be derived from agricultural runoff. In the Potomac River estuary, 31% was attributed to agricultural runoff, while 54% of the nitrogen reaching Wisconsin surface waters has been estimated to be derived from "rural" sources.[68] Williford, *et al.*[114] showed that while relatively large quantities of nitrogen were removed in the leachates from a cropland, less than 0.23% of the nitrogen removed came from fertilizer-nitrogen. However, the sources contributing nitrate to groundwater are not well established. Whether the nitrogen comes from that which is naturally present in soil or is derived from commercial fertilizers, the probability of nitrate escape with leaching water increases with intensified agricultural operations.[68]

Available data are not adequate to permit accurate estimates of nitrogen losses from fertilizers to ground or surface waters.[88] In a dynamic soil-plant system, the behavior of nitrogen is complex. Several processes occur simultaneously in nitrogen transport: fertilizer nitrogen is taken up by plants; organic matter in the soil is mineralized; atmospheric nitrogen is fixed either at the root zone symbiotically, or in atmosphere; nitrogen is leached below the root zone into the soil; and nitrification-denitrification processes are carried out by microorganisms.

However, the Committee on Nitrate Accumulation, National Academy of Sciences,[68] recently estimated that 10%-15% of fertilizer nitrogen

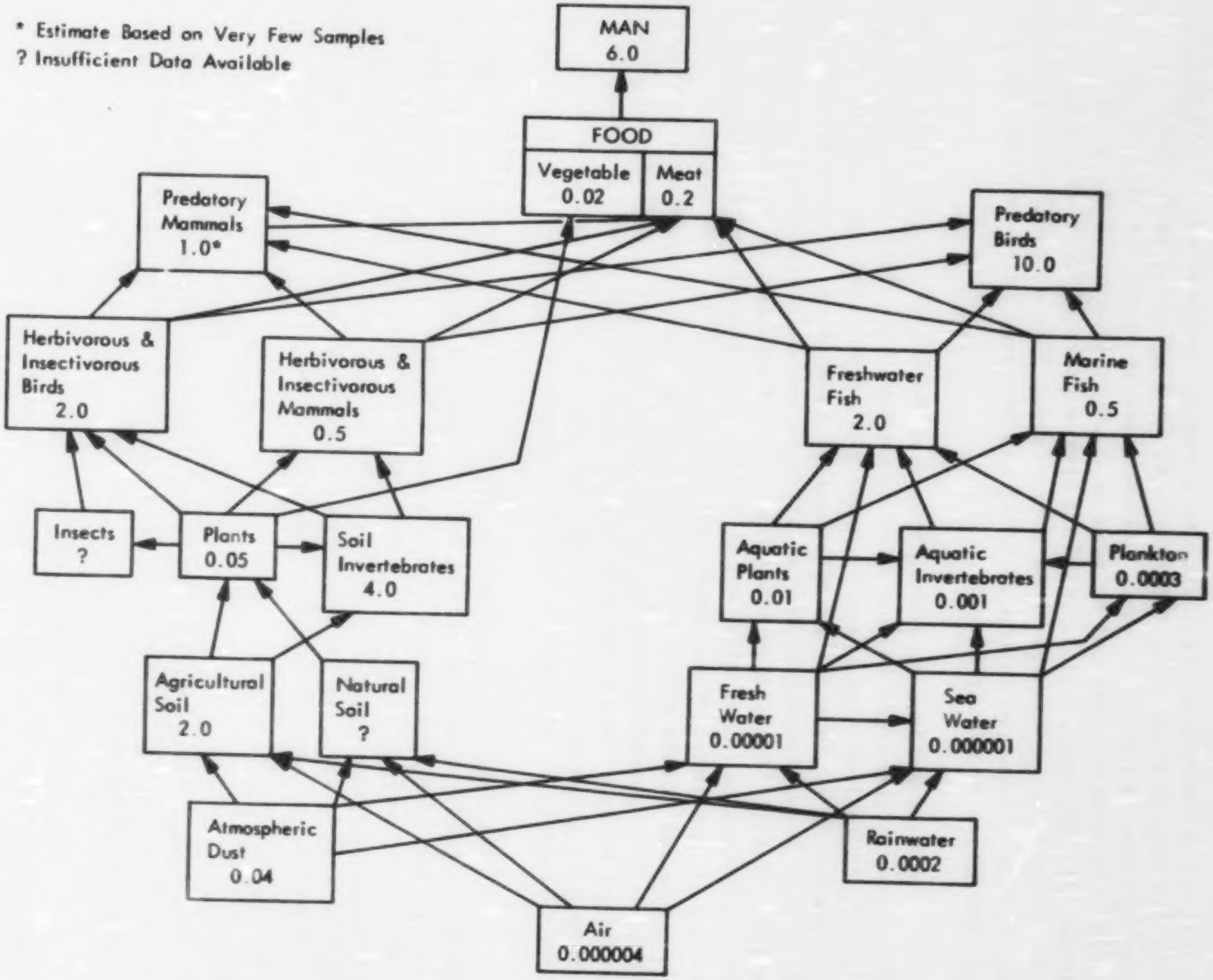

* Estimate Based on Very Few Samples
? Insufficient Data Available
MAN 6.0
FOOD
Vegetable 0.02
Meat 0.2
Predatory Mammals 1.0*
Predatory Birds 10.0
Herbivorous & Insectivorous Birds 2.0
Herbivorous & Insectivorous Mammals 0.5
Freshwater Fish 2.0
Marine Fish 0.5
Insects ?
Plants 0.05
Soil Invertebrates 4.0
Aquatic Plants 0.01
Aquatic Invertebrates 0.001
Plankton 0.0003
Agricultural Soil 2.0
Natural Soil ?
Fresh Water 0.00001
Sea Water 0.000001
Atmospheric Dust 0.04
Rainwater 0.0002
Air 0.000004

Figure 3-1 - Typical Amounts of DDT (ppm) in the Environment (from Edwards[19/])

is lost to waterways, a total from this source, nationwide, of about 1 million metric tons. The total emitted from all sources to the waterways was estimated to be 5.5 million metric tons. Of this total, 2.7 million were transported by erosion, 1.8 million by leaching of native soil nitrogen, and 1.0 million by transport of fertilizers by a combination of processes. A majority (about 90%) of the 5.5 million metric tons discharged to the waterways is believed to be returned to the atmosphere by denitrification.

It is evident from the above considerations, that a minority of the nitrogen discharged to the water is derived from fertilizer nitrogen. However, it follows that rates of discharge of nitrogen may reasonably be expected to be enhanced by agricultural (and other) activities which yield high local concentrations of nitrogen in soils and plant and animal matter. Heavily fertilized croplands are thus expected to be higher-than-average contributors of nitrogen to surface and groundwaters. This conclusion is confirmed by numerous research studies[66,88,106/] which indicate general trends but do not permit precise quantification of yields expected from specific types of agricultural land use. Recovery of fertilizer nitrogen by crops is often no higher than 30%.[90/] The remainder is returned to groundwater by leaching, carried off in surface runoff, retained by soil, or released to the atmosphere by denitrification.

The data presented in the above paragraphs indicate that the processes involved in the cycling of nitrogen in an agricultural ecosystem are complex, and that losses of nitrogen to waterways vary substantially from one agricultural system to another. Knowledge of nitrogen inputs by symbiotic and nonsymbiotic fixation in rainfall, and by mineralization of soil is fragmentary, as is knowledge of losses to waterways, to vegetative or animal products, and to the atmosphere by volatilization and denitrification.

An American Waterworks Association task group[95/] reports that agricultural runoff is the greatest single contributor of nitrogen and phosphorus to water.

The effect of irrigation return flows on water quality is significant. However, this important aspect of water quality was not within the scope of the current study.

3.4.2 Livestock: Animal wastes are a major potential source of water quality degradation. Runoff from barnyard and pastureland may contaminate water supplies, destroy fish and aquatic life in streams, and generally degrade water quality. Nitrate in groundwater in the vicinity of feedlots has been shown to be significantly higher in concentration than at remote locations.[108] It was also found that groundwater under feedlots frequently contained ammonia and organic carbon. Where feedlots are located in humid regions, runoff and percolation combine to enhance the possible loss of nitrogen to waterways.[68]

According to the USDA, 1.8 billion metric tons (2 billion tons) of livestock wastes were produced in the United States during 1972.[98] The potential pollution load in terms of population equivalents is estimated to be 1.9 billion.[107] In other words, the volume of animal waste produced in the U.S. is about 10 times that produced by the human population. About one-half of this waste is produced by animals in confined feeding.[80]

The population equivalent values are an index of potential pollution; actual pollution is substantially less, by an unknown factor. While a majority of livestock wastes is retained on the land, discharges to ground and surface waters are a significant factor in water quality. The extent is strongly influenced by the quality of management at the local level.

3.4.3 Farmland in grass or pasture: About 218 million hectares (540 million acres) of land in the U.S. is used as grassland or pasture. Keller and Smith[61] found that soil below feedlots contained 2,240 kg of nitrate nitrogen/hectare (2,000 lb/acre), while the nitrate nitrogen in the surface soil on adjoining areas ranged from 56 to 168 kg/hectare (50 to 150 lb/acre). They noted that contamination from nitrates remained even after an area was abandoned from animal use. Barnyards, feedlots, and manure piles have been indicated as sources of excessive nitrate nitrogen in shallow wells in Nebraska and Illinois.

Stewart[89] found that nitrate concentrations in soil under feedlots ranged from almost none to more than 5,604 kg/hectare (5,000 lb/acre) in a 6.1 m (20 ft) profile with an average of 1,600 kg/hectare (1,436 lb/acre) for 47 feedlots. Stewart, et al.[90] found that even though the ratio of irrigated lands to feedlots was 200:1, calculations based on the average nitrate content of the irrigated fields (excluding alfalfa) and the rate of water moving through these profiles suggested that 28 to 34 kg of nitrogen/hectare (25 to 30 lb/acre) were lost annually from irrigated fields to the water table. This indicated that although much larger amounts of nitrate/unit area were usually present under feedlots, irrigated lands contributed more total nitrate to the groundwater.

Hutchinson and Viets[52] found that atmospheric ammonia measured near feedlots was as much as 20 to 30 times greater than near control sites. The conclusion was that surface waters in the immediate vicinity of a feedlot can become enriched in nitrogen by absorption of atmospheric ammonia volatilized from the feedlot. These data seem to indicate that not only are runoff and percolation sources of nitrogen from feedlots, but atmospheric nitrogen is a serious consideration as well. The potential water pollution problems from grassland and pastureland may be attributed to three factors: sediment, livestock wastes, and chemicals. Pastures and privately owned grassland contribute to erosion and sediment problems, but the contribution is small with good management practices compared to that from other agricultural and open lands.[15] Erosion from pasture and grassland is of the order of 50 to 100 metric tons/km^2/year (150 to 300 tons/mile^2/year), or about 10% of the erosion from cropland.

Some of the earliest erosion problems in the West developed on badly managed grasslands. The most publicized were those that occurred after heavy sheep grazing in the mountains of the Wasatch Front in Utah, where thunderstorms carried, on an average, the top 7.2 cm (2.9 in.) of soil out of the mountain watershed onto the fertile valley below. A nearby well-managed and undamaged watershed produced less than 0.002% of the sediment eroded from the mismanaged watershed. Improper management can thus lead to very extensive erosion.

The conservation needs are dictated by land use practice. Pastureland needs are based on the condition of the plant cover in relation to the potential of the soil to produce such vegetation, as well as for soil conservation.[15]

The pollution potential from wastes of livestock on pasture may be significant if the topography of the land favors a high rate of runoff into a nearby stream, and if grazing patterns are such that wastes accumulate chiefly in small areas close to surface waters. Limited data are available on the actual impact of livestock wastes on stream water quality in grassland or pasture. However, it appears that the water pollution potential from animal wastes in grazing pastures and grasslands should be minimal under good range management practices.

Studies of chemical treatment of rangeland for brush and weed control using 2,4-D, dicamba, and 2,4,5-T indicate that these chemicals rapidly degrade in the environment when used at recommended rates.[42] The greatest amount of herbicide residue in water appears following runoff shortly after application; residues decrease thereafter with each rain. Picloram does not appear to sorb on soil extensively, nor is it detoxified by microbes. Picloram is also more soluble than other herbicides such as 2,4-D and is one of several herbicides (Fenae, 2,3,6-TBA, and picloram) of similar characteristics which have been observed in subsoils and are a threat to water quality via leaching into subsurface drainage and dissolution in runoff waters. Their use should be restricted in areas where such mechanisms of distribution are favored. Other herbicides such as 2,4-D, are relatively insoluble, sorb on soil, and degrade readily, and the principal threat to water quality arises from possible transport in storm runoff soon after application.

Unlike nitrogen, phosphorus is low in solubility, does not leach readily into the ground, and has a strong affinity for soils, especially clays. The majority of phosphorus that finds its way into the surface water is transported through erosion processes. Hasler[46] found, in an undisturbed mud-water system, that the percentage as well as the amount of phosphorus that is released to the superimposed water is very small. When P^{32} was placed at various depths in the mud, diffusion into the overlying noncirculating water was negligible from depths greater than 1 cm. Thus, most lakes in the U.S. are considered to be phosphorus limited. Any addition of phosphorus through organic wastes or land drainage will trigger algal growth. The loss through drainage of phosphorus of fertilizer origin can be significant. Smith estimated that up to 10% of the phosphorus may be lost through drainage during the year of its application to potato fields using commercial fertilizers.[85]

3.5 Prediction of the Nature and Extent of Nonpoint Pollution from Agriculture

3.5.1 Introduction: There exists considerable literature on the effects of specific pollutants of agricultural origin on water resources. However, very few of these studies directly relate sources to water quality. From a water resources management point of view, prediction methods must relate the nature and extent of nonpoint pollution to the various sources contributing this pollution to water quality. Since a given watershed may contain a large number of agricultural sources, predicting the contribution of pollution from each of these sources is difficult unless a full input-output inventory of pollutants at the boundaries of each source are known, together with the reaction rates during transport and deposition in the water body. At present much potentially useful data are available, but their actual usefulness is limited by uncertainties imposed by physical descriptions of the system.

The methods summarized in this chapter are presented to help the engineer/planner develop strategies for determining the stream pollution from agricultural activities consistent with his resources. Since the presented methods have different levels of complexity, the degree of confidence one can assign to each method varies and is uncertain. However, the methods presented have been tested under actual field conditions and their general validity, in the specific use for which each was designed, has been established. A basic limitation of these methods is the lack of correlation between the nature or the extent of water pollution and the source from which the pollutant originated. Thus, the degree of success that the engineer/planner will have is dictated by his ingenuity and judgment in applying the presently available knowledge to his specific problems.

3.5.2 Prediction methods:

(a) Summary of available methods for sediment prediction: Sediment is characterized as the largest single water polluter. By erosive action, sediment not only depletes valuable land resource, but it also degrades water quality and helps to transport other pollutants. Consequently, a major effort has been spent on the evaluation of methods to predict the levels of sediment pollution contributed from different agricultural sources.

Sediment prediction methods may be summarized under these three categories: (1) erosion; (2) transport; and (3) yield. Table 3-1 shows a partial list of the available methods and some of these are subsequently discussed in detail.

The empirical methods have been developed for all three categories in great detail. However, statistical and simulation methods have been developed primarily for transport and deposition processes.

Water erosion may be broadly classified into two groups:

1. Impact of raindrops on soil, sheet erosion, or further removal of the soil particles by overland flow that can also cut small channels, rill erosion. In either case the field surface is completely smoothed by normal farm tillage methods.

2. A more severe and serious form of soil removal and transport takes place during channel erosion, which is defined as the removal of soil by concentration of flowing water to cause the formation of "channels." The channel erosion removes so much soil that the resulting ditch cannot be eliminated by normal field tillage methods. Gully erosion is closely related to channel erosion and is usually without water except during a rainstorm.

The erosion process of primary concern in predictive methodology is sheet erosion. Ellison[21] has shown experimentally that the quantities of soil carried by raindrop splash during a 30-min period can be expressed as

$$E = K\ (V/30.5)^{4.33}\ d^{1.07}\ (I/2.54)^{0.65} \qquad (3\text{-}1)$$

TABLE 3-1

SUMMARY OF SEDIMENT PREDICTION METHODS

Prediction Method	Process		
	Erosion	Transport	Deposition
1. Empirical			
Ellison[21]	X	-	-
Musgrave[67]	X	-	-
Universal Soil Loss Equation[118]	X	-	-
Einstein Bedload Function[41]	-	X	-
Colby Modified Einstein[41]	-	X	-
Toffaleti Total Load Method[41]	-	X	X
Lacey's Silt Theory[37]	-	X	X
Pemberton Modified Einstein[77]	-	X	-
Reservoir Surveys: ARS SCS Corps of Engineers Bureau of Reclamation U.S. Geological Survey	-	-	X
2. Statistical			
Flaxman[34]	-	-	X
Sediment Rating-Flow Duration: U.S. Geological Survey Bureau of Reclamation Corps of Engineers	-	-	X
Woolhiser's Deterministic Watershed Model[119]	X	X	X
3. Simulation			
ARS Upland Erosion Model[38]	X	-	-
ARS USDAHL-73 Watershed Model[50]	X	X	X
ARS "ACTMO" Chemical Transport Model[74]	-	X	-
Negev's Watershed Model[71]	X	X	X
Stanford IV Model[13]	X	X	X
Hydrocomp Simulation[12]	X	X	X
Huff Hydrologic Transport Model[51]	-	X	-
Royal Institute (Sweden) Hydrologic Model[5]	X	X	X
Snyder's Parametric Hydrologic Model[86]	-	X	X

where E is the soil intercepted in splash samplers (in g), V is the velocity of drops (in cm/sec), d is the diameter of the drop in mm), I is the intensity of rainfall (in cm/hr), and K is a constant. K depends on the numbers and types of samplers and on type of soil. Ellison plotted infiltration-capacity curves for four soil types, as shown in Figure 3-2.

Musgrave[67,94] in 1947 reported the results of analyses of soil loss measurements for some 40,000 storms occurring on small plots in the United States. Their results indicate that the soil loss by sheet erosion varies according to the following relationship:

$$
\begin{aligned}
E, \text{ in } m^3 &= 12 \; IR(S)^{1.35} L^{0.35} (P_{30})^{1.75} \\
E, \text{ in acre in.} &= IR(S)^{1.35} (L)^{0.35} (P_{30})^{1.75},
\end{aligned}
\qquad (3\text{-}2)
$$

where E is the soil loss per year, I is an erodibility factor, measured in centimeters (inches), R is a dimensionless cover factor, S is the degree of slope in percent, L is the length of slope in meters (feet), and P_{30} is the maximum 30-min amount of rainfall, 2-year frequency in centimeters (inches), R is expressed as a ratio of the erosion rate of the field under the existing cover to the erosion rate for a continuous fallow or row crop condition. Equation (3-2) is applicable to long-term average soil losses for broad areas. The Musgrave Equation was shown to be a useful tool for estimating the rate of sheet erosion on agricultural lands in the more humid parts of the country.[40]

A graphical solution of the Musgrave Equation was presented by Lloyd and Eley[60] and is presented in Figure 3-3. The graph was developed primarily for soils located in northeastern United States. Soil factor "I", R factor, and cropping factor "C" were presented under varying conditions. The nomograph presented is useful for an area where 3.2 cm of rainfall in a 30-min period may be expected once in 2 years. For other areas such as soils of the Northwest, similar documents have been prepared by Lloyd and Eley.

Wischmeier and Smith[118] developed in 1966 a prediction equation called "Universal Soil Loss Equation" which takes into account the influence of the total rainfall energy for a specific area rather than the rainfall amount. The limitations of the Musgrave Equation (3-2) were reduced by the development of the Universal Equation so that the new prediction model would:

1. Improve and extend the soil erodibility and cropping factors;

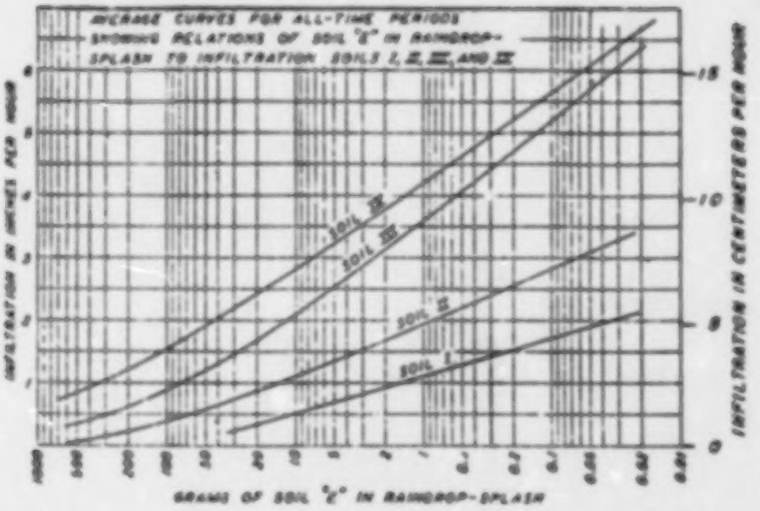


Figure 3-2 - Curves Showing the Relationship of Splash of Soil (E) to Infiltration Capacity for Four Soil Types[21]

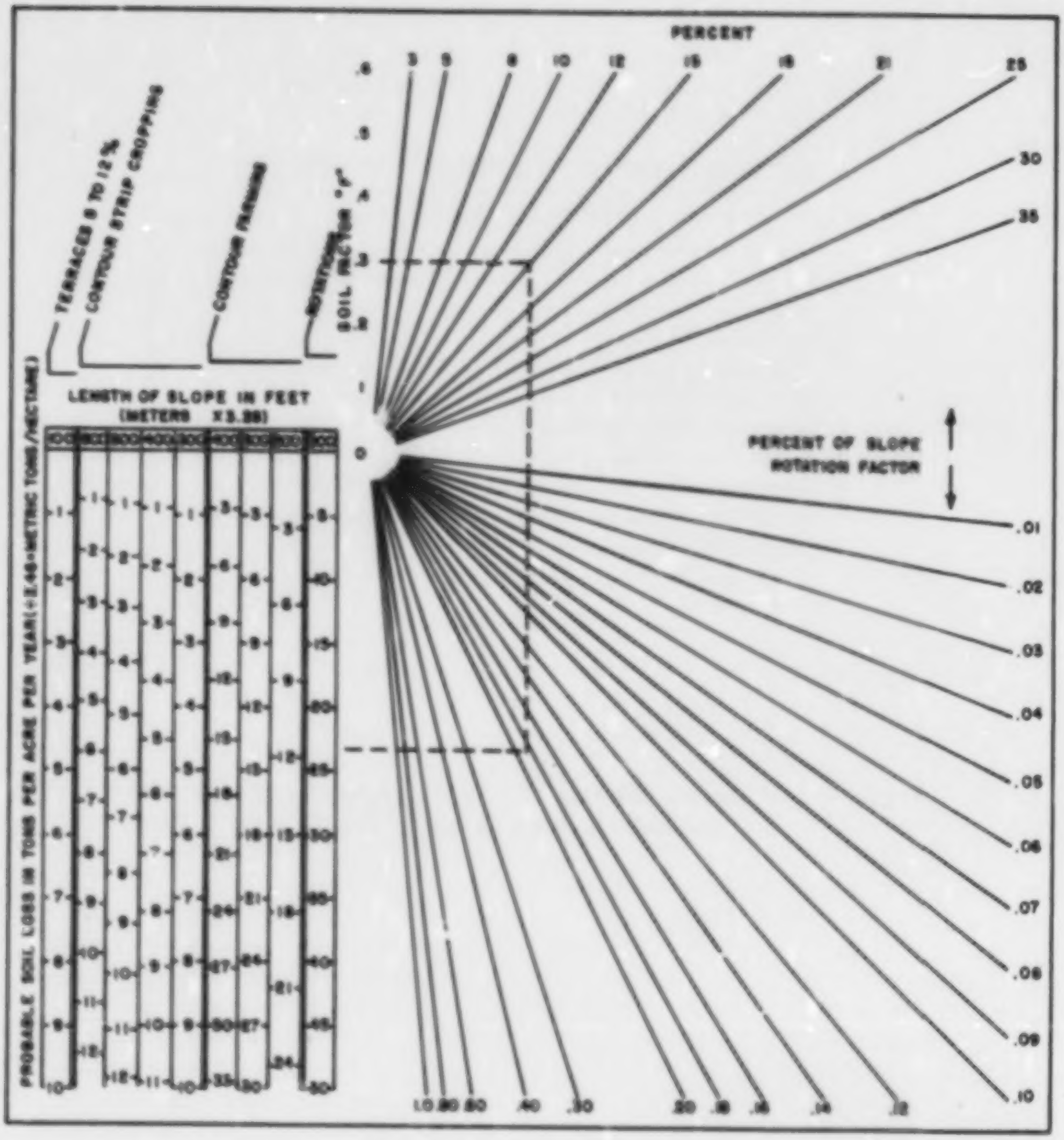

PERCENT
3
5
8
10
12
15
18
21
25
30
35
SOIL FACTOR "F"
.6
.5
.4
.3
.2
.1
0
TERRACES 8 TO 12%
CONTOUR STRIP CROPPING
CONTOUR FARMING
ROTATIONS
LENGTH OF SLOPE IN FEET
(METERS X 3.28)
PROBABLE SOIL LOSS IN TONS PER ACRE PER YEAR (÷2.46=METRIC TONS/HECTARE)
PERCENT OF SLOPE
ROTATION FACTOR
.01
.02
.03
.04
.05
.06
.07
.08
.09
.10
1.0
.80
.60
.40
.30
.20
.18
.16
.14
.12

Figure 3-3 - Nomograph for Probable Soil Loss Using Musgrave Equation[60]

2. Overcome the deficiency of a single rainfall-intensity factor that is not closely related to the number of erosive rainstorms per year;

3. Predict erosion rates by storm season or crop year, in addition to annual averages; and

4. Account for the effects of a multiplicity of cropping sequences, crop yields, and crop residues.

The Universal Soil Loss Equation is

$$A = R\,K\,L\,S\,C\,P\,, \qquad (3\text{-}3)$$

where A is computed average annual soil loss per unit area; R is rainfall factor, or the number of erosion index units in a normal year's rain (the erosion index is a measure of the erosive force of specified rainfall); K is the soil erodibility factor; L is the slope length factor; S is the slope gradient factor; C is the cropping management factor; and P is the erosion control practice factor.

The storm soil loss from cultivated fields is shown to be directly proportional to the product of total kinetic energy E of the storm and its maximum 30-min intensity I. The sum of the computed storm EI values for a given time period is a numerical measure of the erodibility of all the rainfall within that period. Thus, the R factor is expressed as

$$R = \frac{\Sigma EI}{100}\,,$$

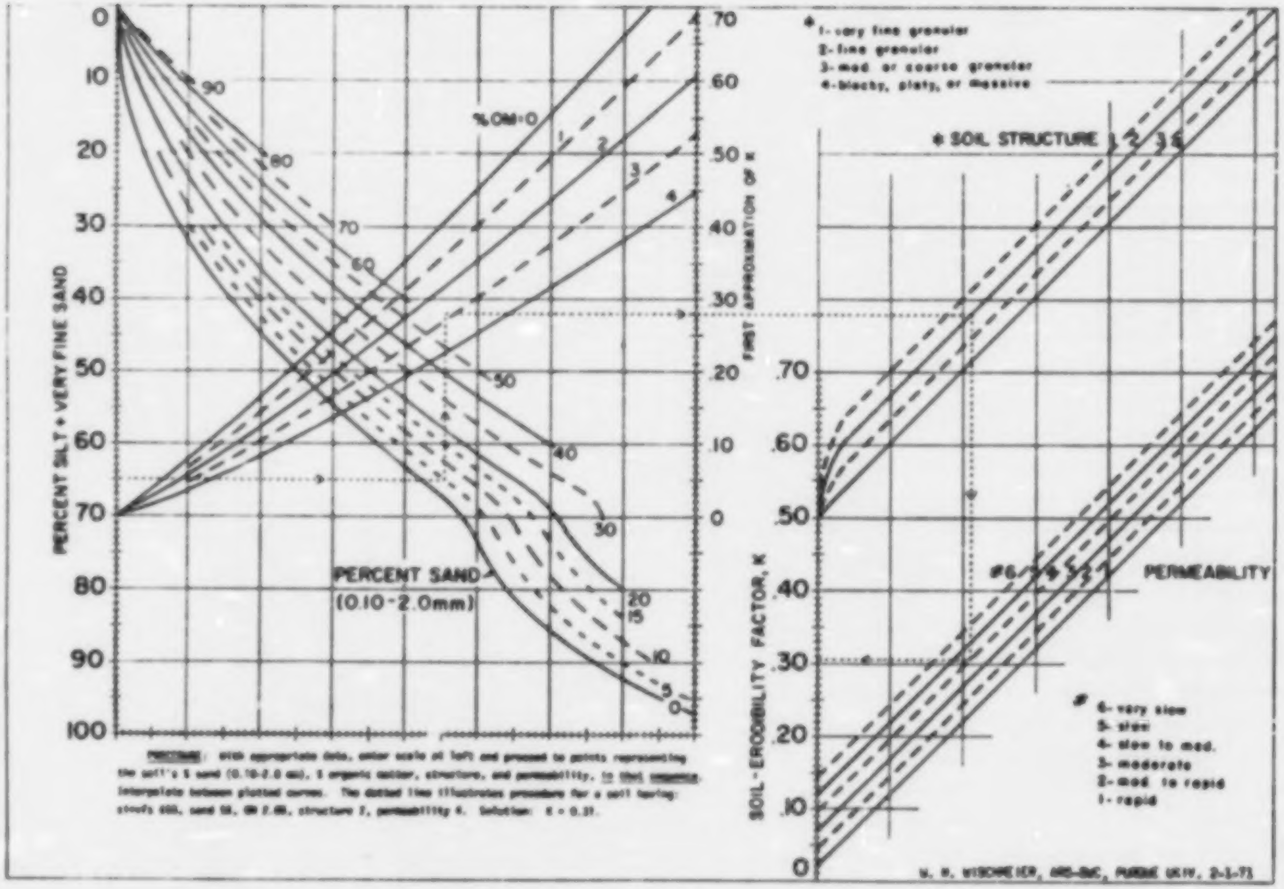
where E is the storm energy in units such as kg-m/m^3 (foot-tons/acre-inches), I is the maximum 30-min intensity. Analyses of U.S. Weather Bureau rainfall statistics are used to develop EI values, which are presented by Wischmeier and Smith.[118] The EI factors have not been evaluated from actual rainfall data for the western regions, and interim EI and R data have been developed by ARS for use in only non-orographic rainfall areas where rainstorms of high energy and intensity are common.[78] The soil erodibility factor K defines the inherent erodibility of the soil. Standard K values were developed for most soil types by the Soil Conservation Service. Several factors influence the erodibility of cohesive soils including texture, soil structure, thickness and permeability, organic matter content, and nature of clay minerals. Typical K values of 23 major soils on which erosion plot studies were conducted have been reported.[118] K factors have been published recently by the SCS for soils in the Southern Region.[100]

The colloidal fraction of soil is the site of most of the chemical and physical reactions taking place in the soil. Variations in soil characteristics greatly influence the soil loss, and the binding capacity of the soil for different pollutants. For example, clay particles have better affinity to colloidal and dissolved minerals than sand or loam. Among clays, montmorillonite clays have higher ion exchange capacities than kaolinite clays. The exchange capacity of kaolinite clay was reported to be 3-15 meq/100 g, while that for montmorillonite clay was 80-100.[65] The erosion rates are not only influenced by the individual soil size fractions in a given surface, but also by the relative stability of the soil after detachment. There appears to be a sorting process in which sands and silts settle out and the clay colloids remain in suspension. The electrochemical, chemical, and physical properties of the clays have to be included in the models describing the erodibility of the soil.

Wischmeier and co-workers[117] in 1971, presented a soil erodibility nomograph for computing the K factor if five soil parameters are known, viz., percent silt, percent sand, organic matter content, structure and permeability. The nomograph is presented in Figure 3-4.

The soil loss is affected by both length and degree of slope. For convenience in the field application, these two factors are combined into a single topographic factor, LS. The soil loss ratio from any given slope conditions can be readily determined by means of a set of graphs developed by the U.S. Agricultural Research Service and shown in Figure 3-5. For slopes and slope lengths greater than those in Figure 3-5, data are extrapolated[78] and presented in Figure 3-6. Data in Figure 3-6 may be adjusted for field conditions based on experience and judgment.

According to Chow,[8] the C factor is a complex factor to evaluate because of the many different cropping and management combinations in a given area. This is further complicated by the variable distribution of rainfall-erosion potential during different periods of crop cover. Fertilizing, mulching, crop residues, crop sequence, and other factors also influence the rate of soil loss. However, field workers in SCS believe that evaluation of C factors is relatively uncomplicated. According to them, the C factors have been worked out for a number of cropping systems by the Soil Conservation Service so that it is relatively easy to make these determinations in the field. The values of C factors vary from 0 to 1, and have been subjectively determined by SCS field personnel. Since usually only a few management combinations are followed in a given area, it would not be a problem unless the watersheds are extremely large.[83]



PROCEDURE: With appropriate data, enter scale at left and proceed to points representing the soil's % sand (0.10-2.0 mm), % organic matter, structure, and permeability, in that sequence. Interpolate between plotted curves. The dotted line illustrates procedure for a soil having: si+vfs 65%, sand 5%, OM 2.8%, structure 2, permeability 4. Solution: K = 0.31.

Figure 3-4 - Soil Erodibility Nomograph

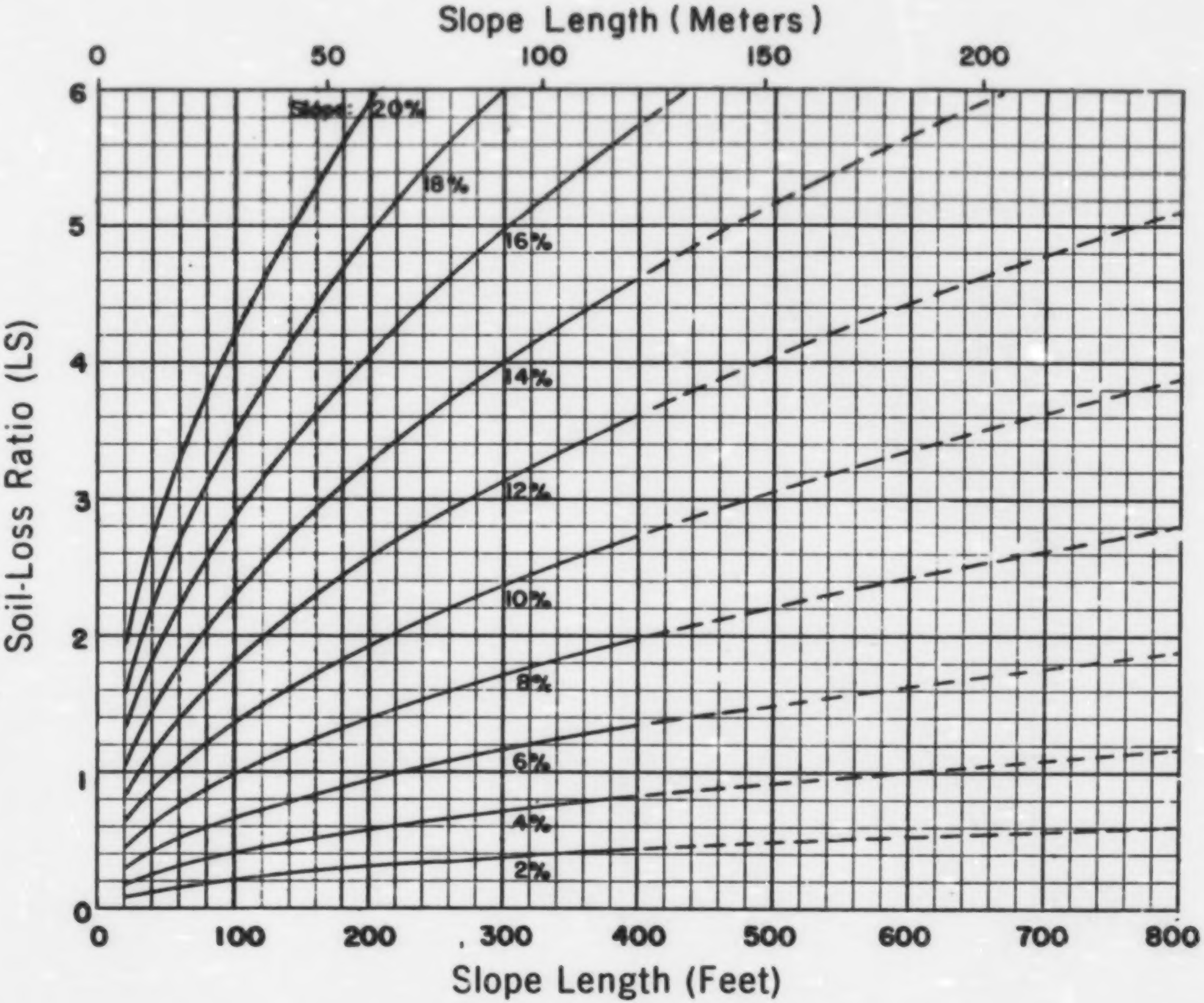


Figure 3-5 - Slope--Effect Chart (Topographic Factor, LS)

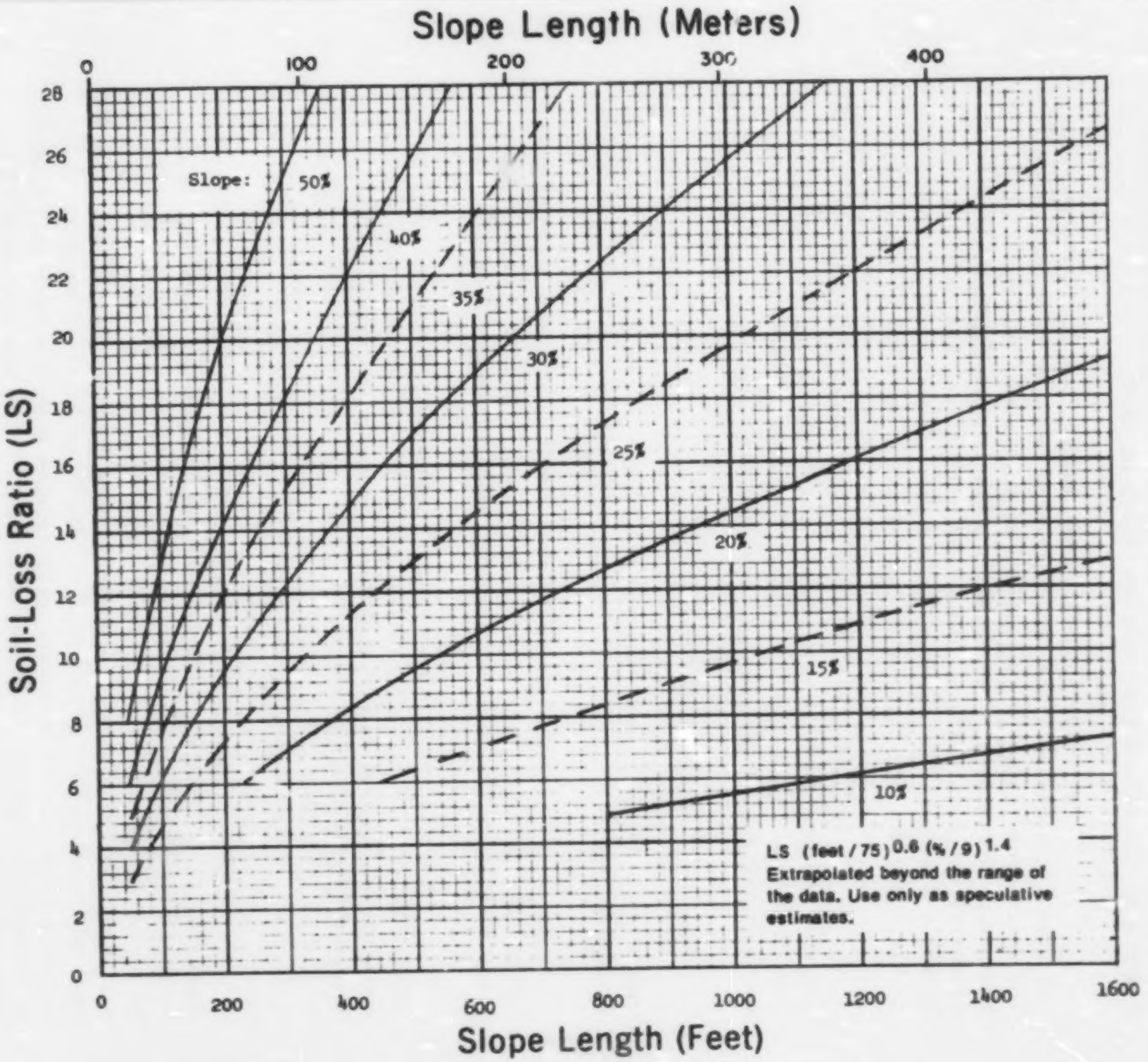


Figure 3-6 - Slope--Effect Chart (Topographic Factor, LS) for Slopes and Lengths Exceeding Those in Figure 3-5

The P factor for croplands depends on the cropping practice such as contour tillage, stripcropping on the contour, and stabilized waterways. It also varies with the slope of land.

The Universal Soil Loss Equation was developed primarily for predicting the soil loss on cultivated lands so that adequate soil and water conservation practices can be initiated. The equation has not been used in the past in watershed studies because factors reflecting the effect of cover on pasture, range, and forest land had not been developed. Recently Wischmeier[81] developed cover factors for these land uses to enable a broader application of the Universal Equation to watersheds.

Williams and Berndt[113] have recently applied the Universal Equation to watersheds by modifying all factors except the rainfall factor. They developed an equation to compute sediment delivery ratios by using multiple regression analysis of watershed characteristics:

$$D = 0.627\ S^{0.403}\ ,$$

where D is the sediment delivery ratio, and S is the slope of main channel in percent.

Erosion from beef cattle feedlots has been predicted by Jeschke and Day[54] by adapting the Universal Equation. The method is being verified with field studies under Illinois conditions.

Recently, the Musgrave Equation (3-2) was reviewed by several workers to reflect the factors in the Universal Equation (3-3). For example, Farnham and co-workers[32] developed in 1966 a modified Musgrave Equation, which is:

$$E = 0.23 \left(\frac{KR}{150}\right) P \left(\frac{R}{100}\right) \left(\frac{S}{10}\right)^{1.35} \cdot \left(\frac{L}{22.1}\right)^{1.35} , \qquad (3\text{-}5)$$

where E is the average soil loss in centimeters per year, KR is the product of soil erodibility factor and the rainfall factor from the Universal Equation (3-3); P is the cover factor; S is slope in percent (with 10% as a base). A comparison of Equations (3-3) and (3-5) by Beer and co-workers[2] showed that the Modified Musgrave Equation gave better estimations of sheet and rill erosion than the Universal Equation on 24 drainage basins. However, only limited use has been made of Equation (3-5).

Another modification of the Musgrave Equation which has been extensively used by the Soil Conservation Service substitutes the

"K" and "C" factors from the Universal Soil Loss Equation for the "P" and "F" factors of the Musgrave Equation.[81] Thus,

$$E = 0.91\ KCR \left(\frac{S}{10}\right)^{1.35} \cdot \left(\frac{L}{22.1}\right)^{0.35} , \qquad (3\text{-}6)$$

where E is the sheet erosion, metric tons per year; K is the soil erodibility factor; C is the cover factor; R is the rainfall factor; S is the land slope in percent; and L is the length of slope in meters.

(b) Sediment transport in streams: Sediment transport in streams has been studied by many investigators. Modern theories of sediment transport are based on studies in the 1930-1955 era by Schokditsch, Meyer, Peter and co-workers; Colby; Einstein; Chien; Toffaleti; Lacey; and Pemberton, among others.

A detailed discussion of the theoretical and practical developments of sediment transport has been published by Graf,[41] and by USDA-Soil Conservation Service.[99]

The theory and mathematical statement of sediment transport is too complex for discussion in this report. Practical methods for dealing with sediment transport are embodied in methods for measurement and prediction of sediment yields.

(c) Sediment yield: The term "Sediment Yield" may be defined as the amount of the eroded soil material that is transported and deposited in a stream either as suspended sediment or as settled bed material, or both.

Sediment yield is dependent on gross erosion in the watershed and on the ability of runoff to transport and deposit eroded material into streams and reservoirs. The yield of a given area varies with changing patterns of precipitation, cover, and land use.

There are several ways to calculate the sediment yield of a watershed, depending on the data available. Average annual sediment yields may be obtained from: (1) gross erosion and sediment delivery ratios; (2) measured sediment accumulations; (3) sediment-rating curves, flow-duration techniques; and (4) predictive equations.

Gross erosion in a drainage area includes sheet and rill erosion, and channel-type erosion (gullies, valley trenches, streambank erosion, etc.). The sediment delivery ratio is that fraction of the soil removed by gross erosion which is delivered to a stream.

$$Y = E(D) \qquad (3\text{-}7)$$

where Y is the sediment yield, E is the gross erosion, and D is the sediment delivery ratio.

Several factors affect sediment delivery ratios: type of sediment sources, size and texture of erodible materials, climate, transport systems, land use, proximity of sediment sources, source size, watershed characteristics, and the nature of depositional areas.

There are no generalized sediment delivery relationships that can be applied to every watershed situation. However, several studies have shown general trends in sediment delivery for specific areas.[99] For example, an analysis of data from widely scattered areas shows that the sediment delivery ratios throughout the country roughly vary inversely as the 0.2 power of the drainage area. This relationship is illustrated by Figure 3-7. Rough estimates of sediment delivery ratios can be made through the use of Figure 3-7, but such estimates should be blended with judgment of other influencing factors such as soil texture, type of erosion, and areas of deposition within the drainage area. Reservoir sediment deposition surveys yield valuable data for establishing sediment yields. In these surveys, the sediment inflow represents the inflow between survey periods, which may not represent a long-time average inflow, depending on the hydrologic period between surveys. It must be understood that reservoir deposition and sediment yield are not synonymous. The amount of accumulated sediment is only a fraction of the sediment yield and must be divided by the reservoir's trap efficiency to determine the yield. The sediment yield of an unmeasured watershed may be estimated from that of a measured watershed in the same or similar area by adjusting the ratio of the drainage area raised to the 0.8 power:[91]

$$S_e = S_m\left(\frac{A_e}{A_m}\right)^{0.8} , \qquad (3\text{-}8)$$

where S_e is the sediment yield of unmeasured watershed; S_m is the sediment yield of measured watershed, i.e., measured annual sediment deposition ÷ trap efficiency of surveyed reservoir; A_e is the drainage area of unmeasured watershed; and A_m is the drainage area of measured watershed.

The relationship shown in Equation (3-8) must be confined generally to the humid areas east of the Rocky Mountains.[49]

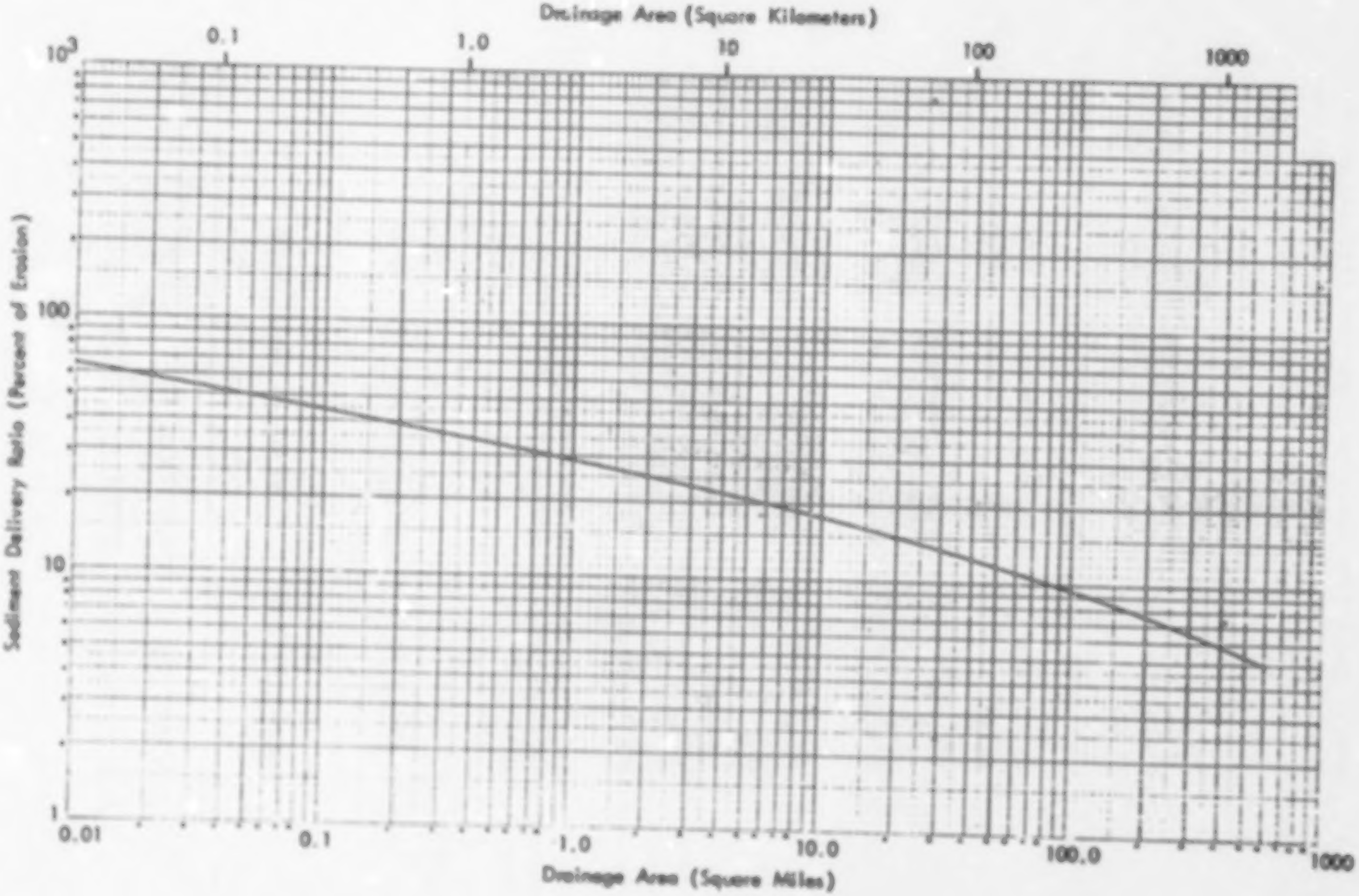


Figure 3-7 - Sediment Delivery Ratio vs. Size of Drainage Area[99/]

Several regression equations have been obtained for different regions based on field data to relate delivery ratio with drainage area and other factors: For the Southeast Piedmont region:[94]

$$\log D = 3.95 - 0.23 \log 10\,A$$
$$+ 0.51 \log \frac{R}{L} - 2.79 \log B \quad . \qquad (3\text{-}9)$$

For western Iowa and northeast Missouri, based on a study of 26 reservoir watersheds:[94]

$$\log D = 1.140 - 0.258 \log A \qquad \text{(Iowa data - Mule Creek)}, \qquad (3\text{-}10)$$

$$\log D = 0.868 - 0.239 \log A \qquad \text{(Missouri data)}. \qquad (3\text{-}11)$$

For the Red Hills area of south Kansas, western Oklahoma, and western Texas:[81]

$$\log D = 2.943 - 0.824 \log \frac{R}{L} \quad , \qquad (3\text{-}12)$$

where D is the sediment delivery ratio, percent; R/L is the dimensionless relief basin length ratio; A is the drainage area in hectares; and B is the weighted mean bifurcation ratio (number of streams of any given order ÷ number in the next higher order).

A comparison of several graphical relationships indicated the drainage area to be a better indicator of sediment delivery ratio.[81] Thus, the equation:

$$\log D = 1.534 - 0.142 \log A \qquad (3\text{-}13)$$

appears to represent a large number of drainage areas studied.

Recently Flaxman[35] has developed a regression equation to predict sediment yield in terms of four measurable independent factors for 11 western states of the U.S. The regression equation is:

$$\log(4.75Y + 100) = 6.21 - 2.19 \log(X_1 + 100) + 0.06 \log(X_2 + 100)$$
$$- 0.02 \log(X_3 + 100) + 0.04 \log(X_4 + 100) \quad , \qquad (3\text{-}14)$$

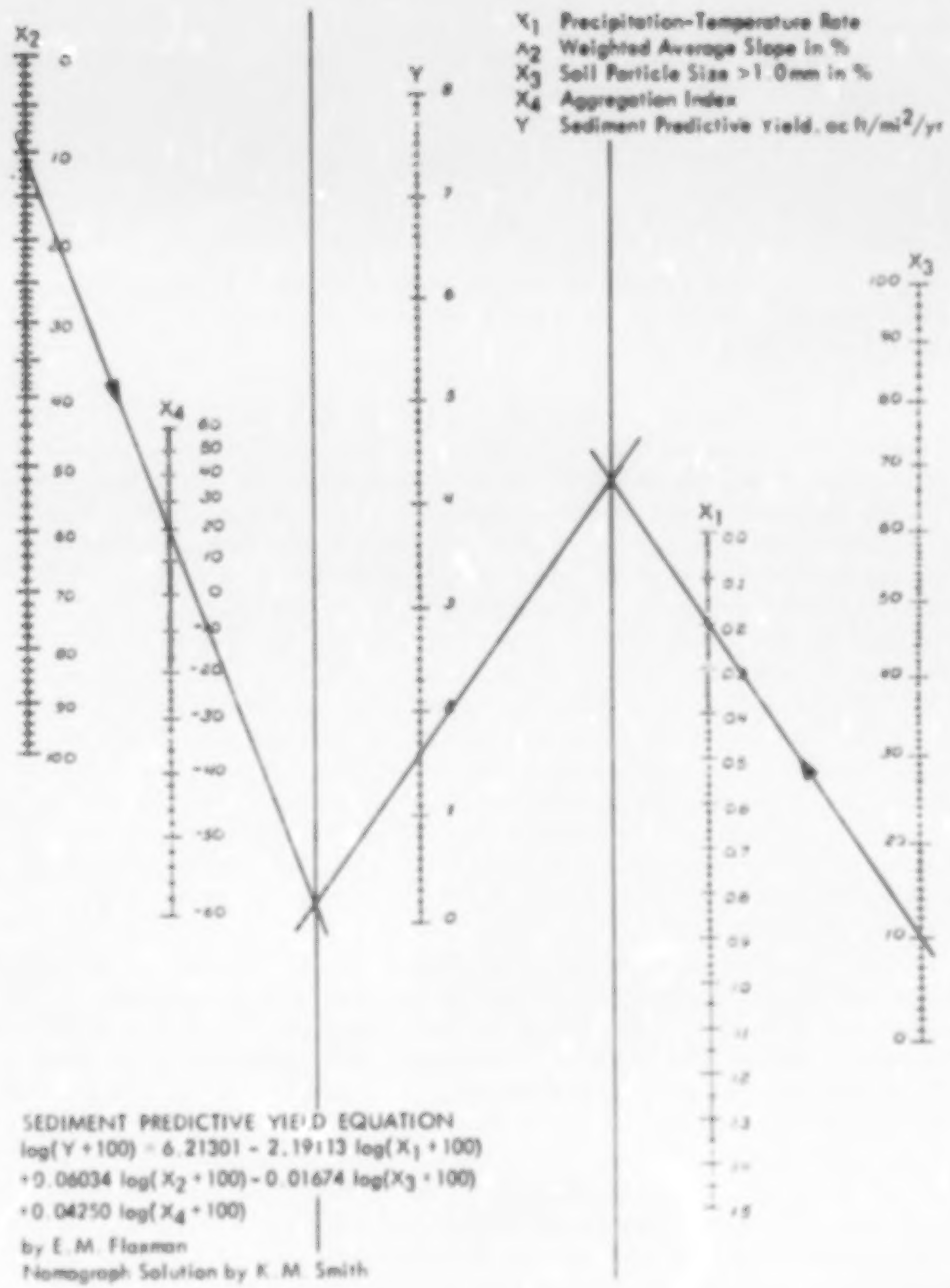
where Y is the sediment yield in m^3/hectare/year; X_1 is the climate factor (average precipitation, cm ÷ [0.71 (average annual temperature, °C) + 12.8]; X_2 is the topography factor [weighted average watershed slope, percent = Σ (area of contour interval x percent slope) ÷ total area]; X_3 is the coarseness of soil particles [percent of soil particles coarser than 1 mm in the surface top 5 cm (2 in.) of the soil profile]; and X_4 is the soil aggregation index [percent clay-size particles 2μ or finer in top 5 cm (2 in.) of the soil profile]. A nomograph is used to solve for Y in Equation (3-14), and is presented in Figure 3-8.[36]

Equation (3-14) was found to best fit the observed data when the computed yields are less than 1.4 m^3/hectare/year (0.3 acre-ft/mile^2/year).

The predicted yields from Equation (3-14) exclude the effect of gully and stream channel erosion, which must be added for computing the gross yield.

Another method of predicting sediment yield is based on sediment-discharge rating curve and flow duration methods, employed by the Bureau of Reclamation.[97] This method requires concurrent measurement of streamflow and sediment amount. This method of obtaining data is difficult and expensive on small streams. However, considerable savings can be realized if samples are obtained during flood flow, instead of daily sampling. Some samples are needed at lower flows in addition to the flood flows. Data for developing flow-duration curves are usually obtained from a stream gaging station, near the sampling site. As examples, a sediment-discharge rating curve and a flow-duration curve for the San Juan River are presented in Figures 3-9 and 3-10, respectively. These figures were developed from 19 years of sediment sampling data from the San Juan River at Bluff, Utah. The streamflow records in this case encompass the same time period as the sediment records.[91,97] Such parallel records are often not available, and extension of the sediment rating curve becomes an exercise of engineering judgment.

Thus, Strand[91] calculated the yield rate in the San Juan River Valley for the spring season to be 2.91 m^3/hectare/year (0.612 acre-ft/mile^2/year), and 4.03 m^3/hectare/year (0.847 acre-ft/mile^2/year) for other seasons. In these calculations, two assumptions were made: (1) correction for unmeasured sediment was assumed to be 10% and 20%; and (2) the sediment density was assumed to be the same as the density of water. The reason for two correction factors on unmeasured sediments is due to the sizes of sediment and volume of water during the spring runoff which are different than those during the rest of the season. Direct measurement of density by using core samples would yield more accurate prediction. Correction for bedload may be made from Table 3-2.[91,97]



X_1 Precipitation-Temperature Rate
X_2 Weighted Average Slope in %
X_3 Soil Particle Size >1.0mm in %
X_4 Aggregation Index
Y Sediment Predictive Yield, ac ft/mi^2/yr

SEDIMENT PREDICTIVE YIELD EQUATION

$$\log(Y+100) = 6.21301 - 2.19113 \log(X_1+100) + 0.06034 \log(X_2+100) - 0.01674 \log(X_3+100) + 0.04250 \log(X_4+100)$$

by E. M. Flaxman
Nomograph Solution by K. M. Smith

Figure 3-8 - Nomograph Solution of Equation 3-14[36/]

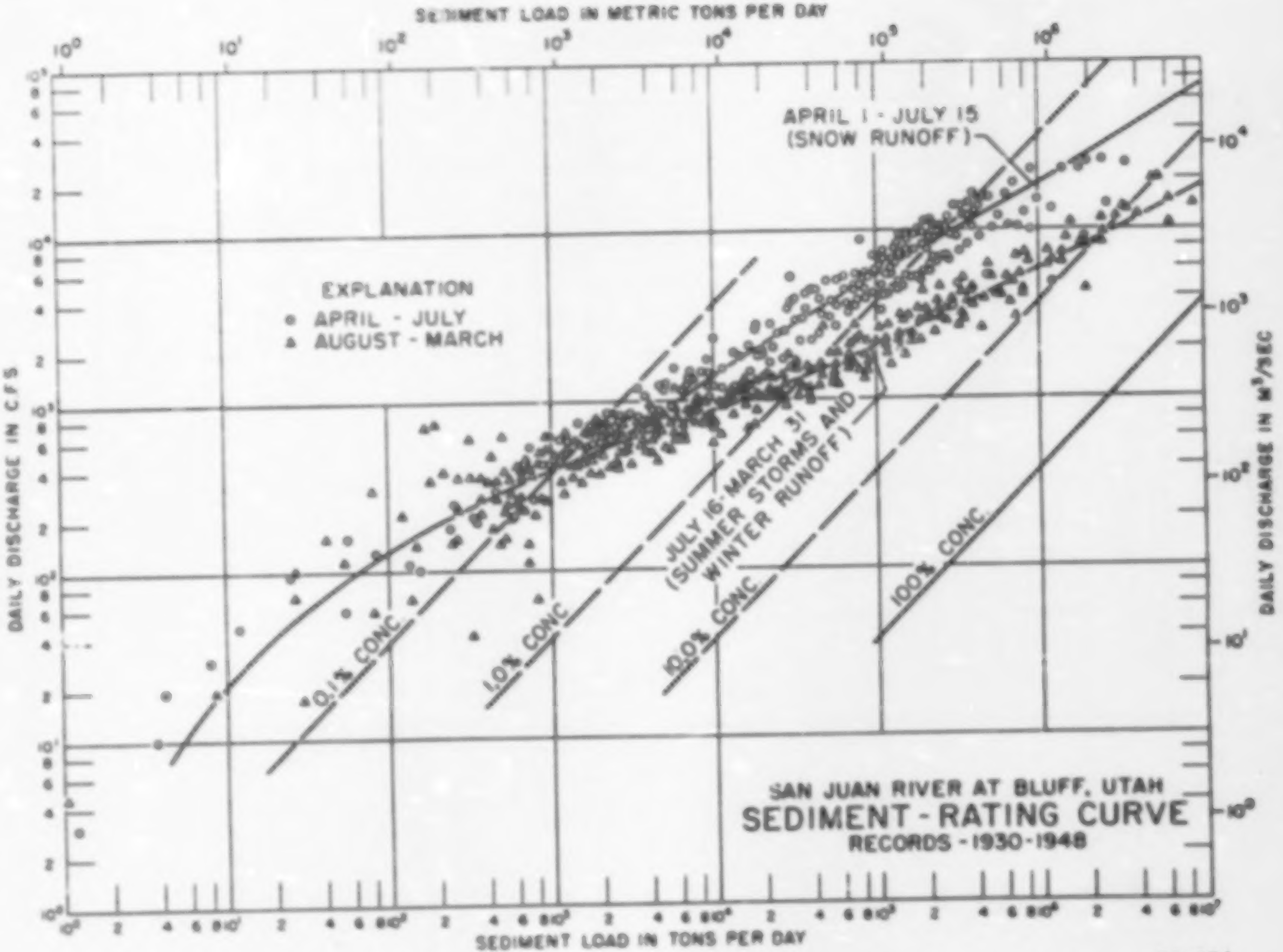


Figure 3-9 - Sediment Discharge Rating Curves for San Juan River at Bluff, Utah[91,97/]

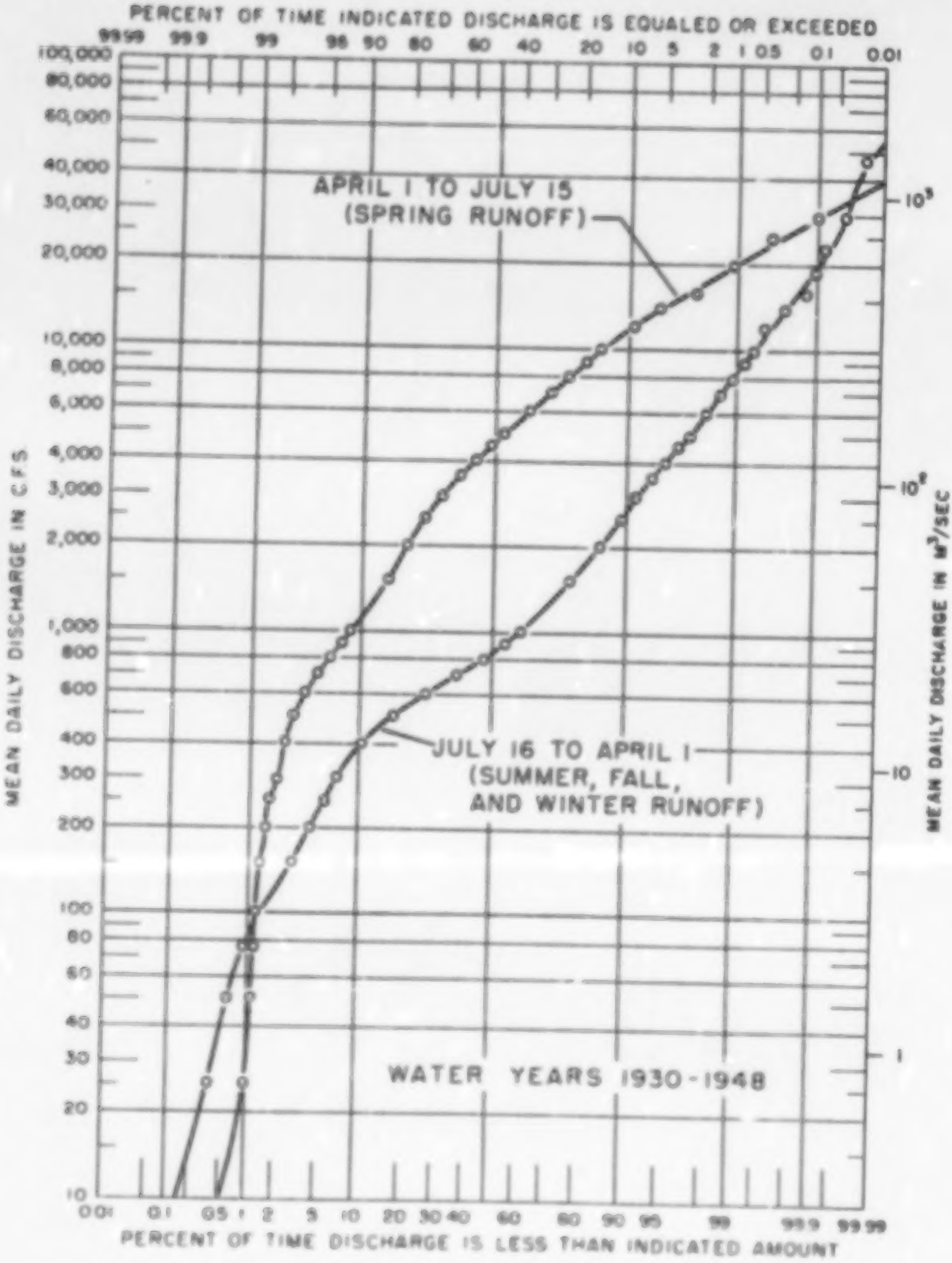


Figure 3-10 - Seasonal Flow-Duration Curves for San Juan River at Bluff, Utah[91,97]

TABLE 3-2

BED LOAD CORRECTION TABLE[91,97]

Concentration of Suspended Load	Type of Material Forming the Bed of the Stream	Texture of the Suspended Material	Percent Bed Load in Terms of Measured Suspended Load
Less than 1,000 ppm	Sand	Similar to bed of stream	25 to 150%
Less than 1,000 ppm	Compacted clay, gravel, cobbles and boulders.[a]	Small amount of sand	5 to 12%
1,000 to 7,500 ppm	Sand	Similar to bed of stream	10 to 35%
1,000 to 7,500 ppm	Compacted clay, gravel, cobbles and boulders.[a]	25% sand or less	5 to 12%
Over 7,500 ppm	Sand	Similar to bed of stream	5 to 15%
Over 7,500 ppm	Compacted clay, gravel, cobbles and boulders.[a]	25% sand or less	2 to 8%
Any concentration	Clay and silt, unconsolidated	Silt and clay	Less than 2%

---

[a] The bed material of the stream may contain any one or all of these very fine or coarse-sized sediments.

Sediment yield rating curves can be constructed from reservoir survey data[16,32] from watersheds having similar climatic, topographic, and geologic properties. Figure 3-11 is such a curve developed for the arid Southwest.[91] The relationship, sediment yield is proportional to (drainage area)$^{0.8}$, appears to be valid for several basins with similar characteristics.

Flaxman[34] used suspended sediment load measurements for evaluating the sediment yield. Figure 3-12 shows the relationship between discharge and suspended sediment concentration (sediment-discharge rating curve) for San Ramon Creek, California.

Among the most complex of discharge and suspended sediment concentration relationships existing in the West are those occurring in the eastern Washington and Oregon area. Figure 3-13 shows a plot of data from the Walla Walla River in southeastern Washington. The segment (2) on the curve in Figure 3-13 reflects a rate of increase in sediment concentration many times the rate of increase of discharge. This unusually large rate is attributable to an acceleration of soil erosion with the thawing of the soil frost. Soil losses as much as 670 metric tons/hectare/year (300 tons/acre/year) have been measured as rain or snowmelt rills the slopes that are bare or are in poor cover.

Segment (1) in the curve (Figure 3-13) is interpreted as the result of return flow from irrigation. The relatively high concentration of sediment during the very low flows is diluted as discharge increases.

Segment (3) in Figure 3-13 is indicative of sediment yields under conditions of abnormally high discharge rates. That is, sediment becomes available at rates disproportionate to the rate of increase in discharge. This indicates the error that may occur if a straight line relationship is extended too far. On the other hand, added stresses exerted on a watershed by a storm of rare occurrence (20-50 year storm) may expose new sources of sediment, and result in abnormally high sediment yields. To use these procedures, an array of data on sediment concentrations must be available to accompany discharge data, the latter preferably at a wide range of flows. Sufficient knowledge of the watershed should be available to relate sources of sediment to the characteristics of the plotted curves of data.

By relating watershed characteristics to suspended sediment concentration-discharge relationships, knowledge can be built up to aid in obtaining the answers to the following questions:

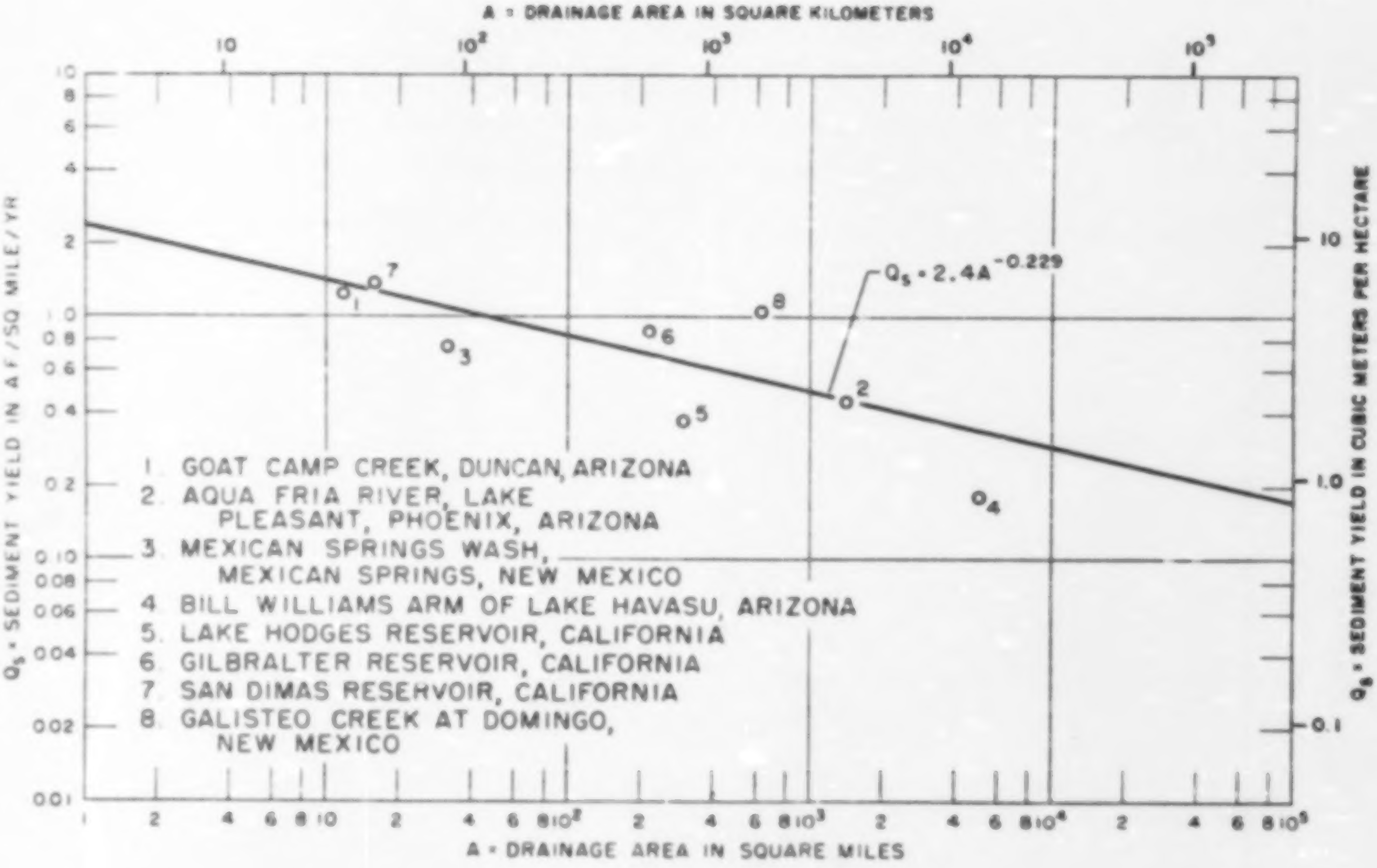


Figure 3-11 - Sediment Yield vs Drainage Area for the Southwest[91/]

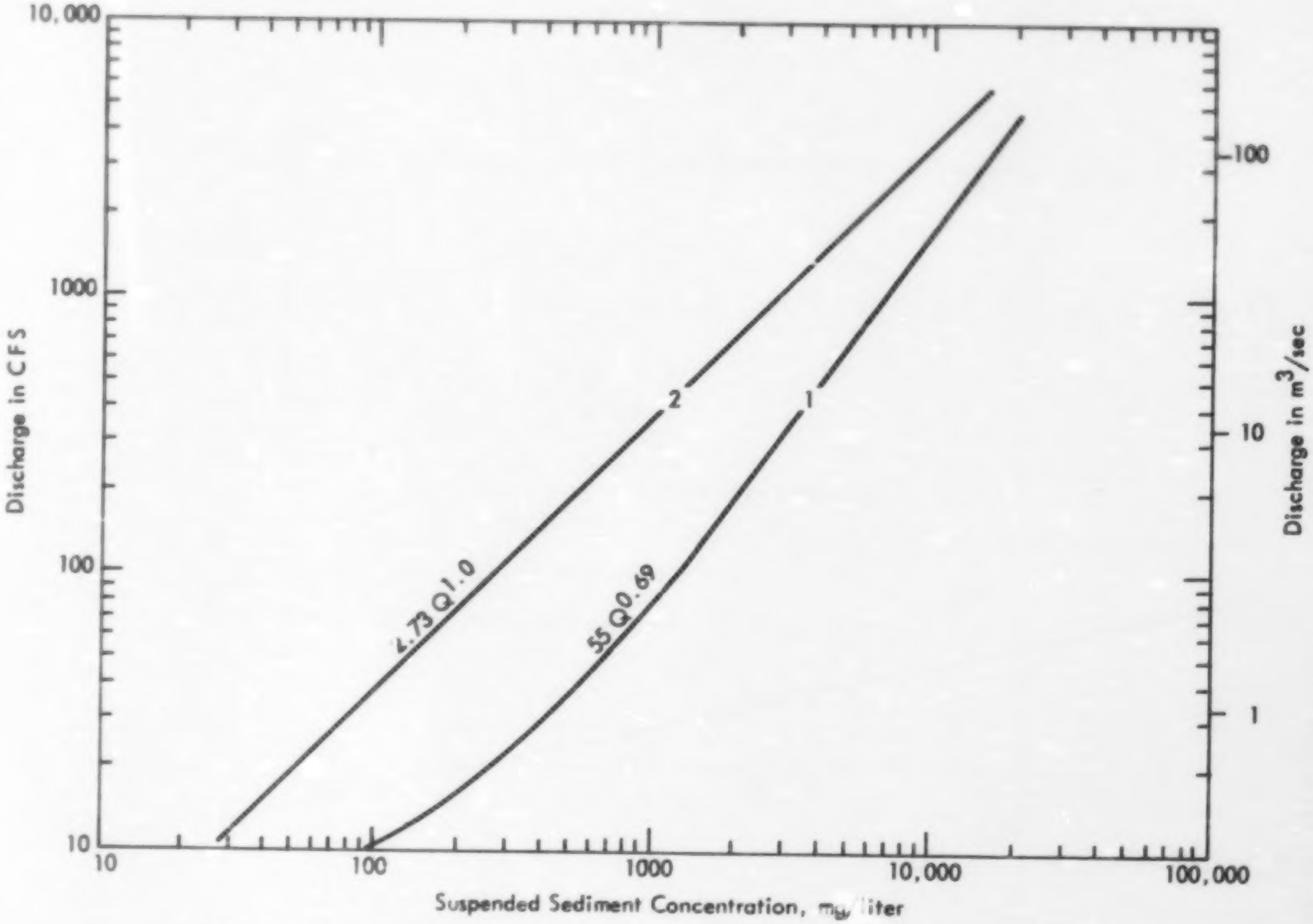


Figure 3-12 - San Ramon Creek at Walnut Creek, California, Relationship between Discharge and Suspended Sediment Concentration.

1. Relationship between measured data, 1955-58.
2. Theoretical relationship assuming no bank cutting existed 34/

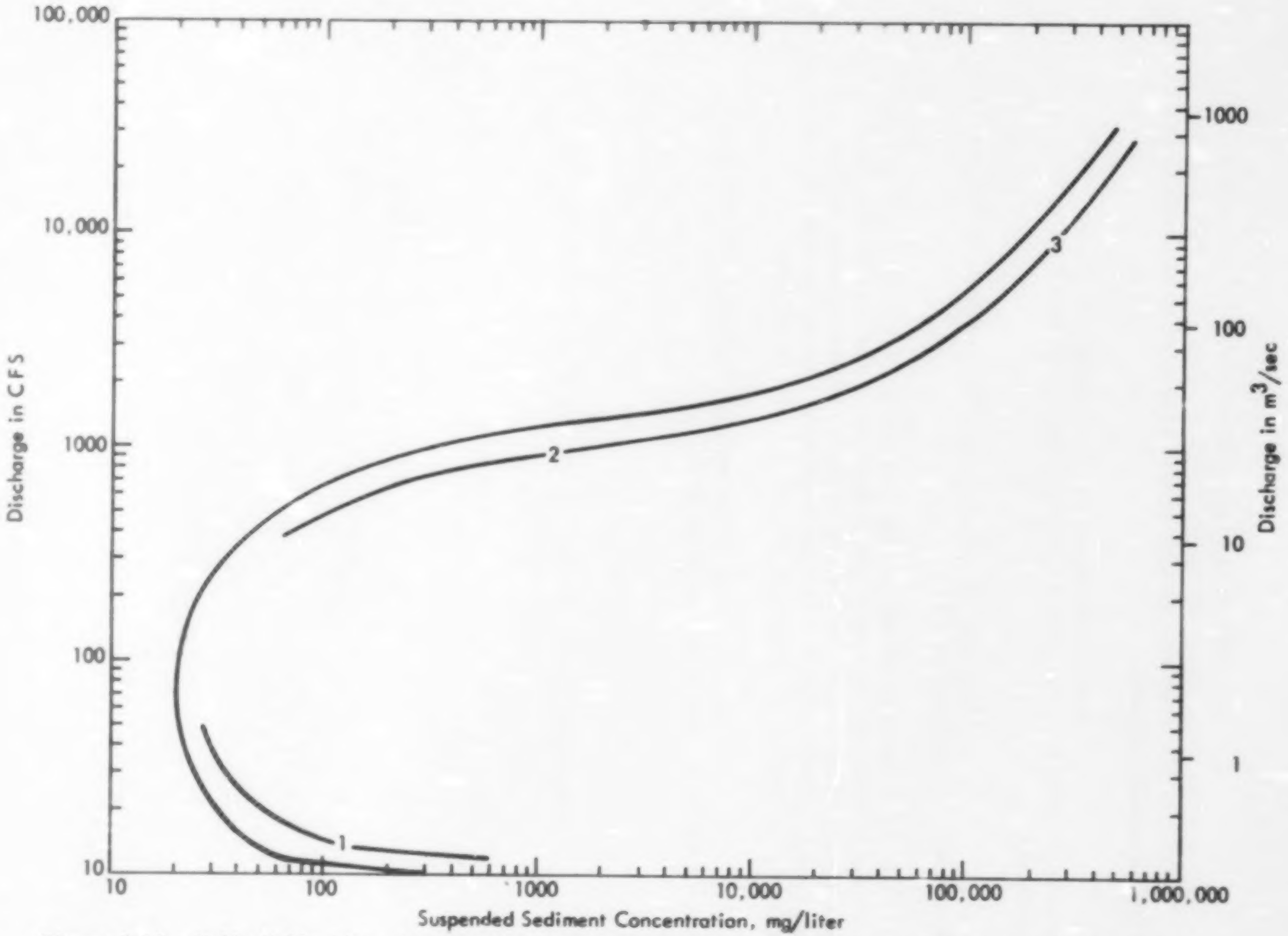


Figure 3-13 - Walla Walla River Near Touchet, Washington, Relationship Between Discharge and Suspended Sediment Concentration (Generalized): (1) Reverse relationship occurs at time of return flow from irrigation; (2) Accelerated increase in sediment concentration relative to discharge occurs at time of soil frost thaw; (3) Sediment concentration increasing at a declining rate relative to discharge 34/

1. What are the dominant sources of sediment yield?

2. What is the approximate effect of these sources on sediment concentrations?

3. What is the increase in sediment yield under disturbed watershed conditions relative to yields under undisturbed watershed conditions?

4. What are the effects of land treatment on the reduction of erosion and sediment yield?

Because of the unusual conditions existing in the arid Southwest, a new rating method was suggested by the Pacific Southwest Interagency Committee[75/] in 1968 to predict sediment yields, and to supplement actual sediment yield measurements. These recommendations apply to watersheds of more than 30 km^2 (10 $mile^2$) in size.

The sediment yields are divided into five classes with corresponding ratings shown in Table 3-3.

TABLE 3-3

CLASSIFICATION OF SEDIMENT YIELD FOR PACIFIC SOUTHWEST[75/]

Class	Average Annual Sediment Yield m^3/hectare	(acre-feet/$mile^2$)	Rating
1	>15	(>3.0)	>100
2	5 - 15	(1.0-3.0)	75-100
3	2.5-	(0.5-1.0)	50- 75
4	1 -2.5	(0.2-0.5)	25- 50
5	< 1	(<0.2)	0- 25

Nine factors were recommended for consideration in determining the sediment yield classification. These are geology, soils, climate, runoff, topography, ground cover, land use, upland erosion, and channel erosion and sediment transport. The characteristics of each of the nine factors which give that factor high, moderate, or low potential for sediment yield are shown in Table 3-4. The sediment yield characteristic of each factor is assigned a numerical value representing its relative significance (weight) in the yield rating, which is the sum of values for each of the nine factors. Each of the nine factors shown in Table 3-4 are paired influences with the exception of topography. That is, geology and soils are directly related as are climate and runoff, ground cover and land use, and upland and channel erosion. Ground cover and land use have a negative influence under better than average conditions. Their impacts on sediment yield are therefore indicated as a negative influence when providing better protection than the average.

In most cases, high values for the A through G factors should correspond to high values for the H (upland erosion) and/or I (channel erosion) factors.

Although only the high, moderate, and low sediment yield levels are shown in Table 3-3, interpolation between these values may be made.

Thus, a total rating of 92 would indicate that the sediment yield is in Class 2, i.e., 5-15 m^3/hectare/year (1-3 acre-ft/mile^2/year). This compares with a sediment yield of 9.3 m^3/hectare/year (1.96 acre-ft/mile^2/year) as the average of a number of measurements in this area.

(d) Areas of application: The Bureau of Reclamation, in the design of water supply projects, utilizes the sediment rating curve-flow duration method for predicting the sediment yield in reservoirs. Other methods used by the Bureau include sediment yield rating curves from reservoir survey information, the suspended sediment method, and erosion prediction equations such as the Modified Universal Soil Loss Equation.

In the design of open channels, the Bureau estimates total bed material discharge using the modified Einstein bedload function developed by Colby,[8] or the transport of bedload based on the mean measured stream velocity as reported by Colby.[8] Recently, Pemberton[77] published the Bureau's procedures, using adjustments to the Einstein bedload function, for predicting transport rates of total bedload of sand-size or coarser material, by size fractions. Pemberton concluded that corrections were needed in the Einstein bedload function for measured velocity and

TABLE 3-4

SEDIMENT YIELD LEVELS AND THEIR RATINGS FOR A WATERSHED OF 39 km^2 (15 $mile^2$) IN WESTERN COLORADO[75]

	Factors	Sediment Yield Level	Rating	Potential
A	Surface geology	Marine shales	10	10
B	Soils	Easily dispersed, high shrink-swell characteristics	10	10
C	Climate	Infrequent convective storms, freeze-thaw occurrence	7	10
D	Runoff	High peakflows, low volumes	5	10
E	Topography	Moderate slopes	10	20
F	Ground cover	Sparse, little or no litter	10	10
G	Land use	Intensively grazed	10	10
H	Upland erosion	More than 50% rill and gulley erosion	25	25
I	Channel erosion	Occasionally eroding banks and bed, but short flow duration	5	25
		Total	92	130

for another parameter, namely the unmeasured portion of the sediment load, by using the bedload or total load formulae. If sufficient data are not available, the Bureau recommends adjustments to the suspended sediment loads using the data shown in Table 3-2.[91]

Because of the varying age of sediment in a reservoir, its density will vary from time to time. An accurate estimation of density is important in predicting the sediment yields in mass units. The most accurate and direct method would be to weigh representative core samples. However, this is not always possible. Figure 3-14 shows the variation of dry unit weight of sediment with depth using both core sampler and gamma probe.[57] The Bureau of Reclamation procedure for density correction is presented in Table 3-5,[91] which was prepared using foot-pound units. An equivalent table using the metric system is shown in Table 3-6. It must be emphasized that in estimating the suspended sediment load, variation of load with season is highly significant, as shown in Figure 3-15,[58] and that "average" values do not accurately reflect occasional high loading rates.

Holeman[69] summarized procedures used in the SCS to estimate sediment yields. These procedures include gross erosion and sediment delivery ratios, predictive equations for specific areas, suspended sediment load by sediment-discharge rating curves, and reservoir sediment deposition surveys. These methods have already been discussed.

The Corps of Engineers' methods for predicting sediment yields were summarized recently by Livesey,[59] who emphasized the need for long-term reservoir survey data, especially for small watersheds.

(e) Simulation models: Several mathematical models have been proposed to simulate the environmental conditions of a stream and to predict the changes from upstream conditions. The hydrological model due to Negev,[71] Stanford IV Watershed Model,[13] Hydrocomp Model,[12] Royal Institute, Sweden Hydrologic Model,[5] Huff's Hydrologic Transport Model,[51] USDA Hydrologic Laboratory Model, USDAHL-73,[50] Snyder's Parametric Hydrologic Model,[86] Woolhiser's Deterministic Model,[119] ARS "ACTMO"--Agricultural Chemical Transport Model,[74] and the Foster-Meyer Upland Erosion Model,[38] are but a few examples of simulation techniques which employ modern high speed digital and analog-digital computers. Recently, Lunin[62] discussed the need for water quality models in agriculture. He emphasized the systems approach for study of hydrologic systems of watersheds, as monitoring water quality by itself cannot always adequately pinpoint the source of pollution.

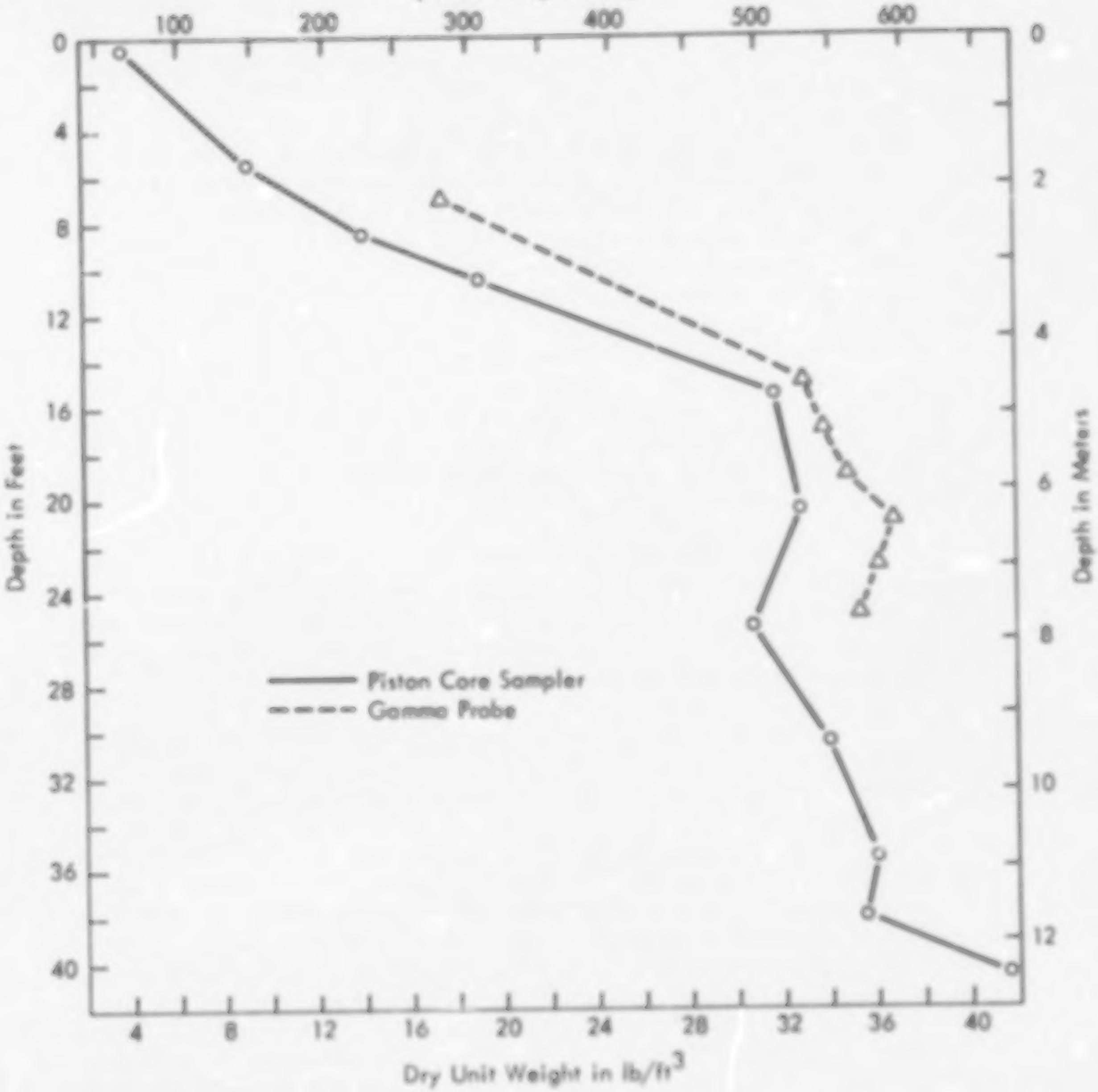


Figure 3-14 - Depth-Density Relation of Reservoir Sediment[58]

TABLE 3-5[91]

UNIT WEIGHT OF SEDIMENT IN SEDIMENT VOLUME COMPUTATIONS

TYPE OF RESERVOIR OPERATION	INITIAL WEIGHTS (Lara and Pemberton) W_1			K FACTORS (Lane and Koelzer) K		
	Clay	Silt	Sand	Clay	Silt	Sand
I. Sediment always submerged or nearly submerged	26	70	97	16.0	5.7	0
II. Normally moderate to considerable reservoir drawdown	35	71	97	8.4	1.8	0
III. Reservoir normally empty	40	72	97	0	0	0
IV. River bed sediments	60	73	97	0	0	0

Unit Weights after various Units of Time

$$W_{\text{ave time (T)}} = W_1 + .4343K\left[\frac{T}{T-1}(\log_e T) - 1\right]$$

$W_{10} = W_1 + .675K$

$W_{20} = W_1 + .938K$

$W_{30} = W_1 + 1.093K$

$W_{40} = W_1 + 1.210K$

$W_{50} = W_1 + 1.298K$

$W_{60} = W_1 + 1.372K$

$W_{70} = W_1 + 1.438K$

$W_{80} = W_1 + 1.493K$

$W_{90} = W_1 + 1.542K$

$W_{100} = W_1 + 1.588K$

Sample Computations

Size Analysis:
Clay = 23%
Silt = 40%
Sand = 37%

100 Year Sediment Storage
Compute K
$K = 84\ (0.23) + 1.8\ (0.40) + 0$
$K = 1932 + .72 = 2.652$

Reservoir Operation: Type II
Compute W_1
$W_1 = 35\ (0.23) + 71\ (0.40) + 97\ (0.37)$
$W_1 = 8.05 + 28.4 + 35.89 = 72.3$ lb/cu ft

$W_{100} = W_1 + 1.588\ K$
$W_{100} = 72.3 + 1.588\ (2.652)$
$W_{100} = 72.3 + 4.2 = 76.5$ lb/cu ft

TABLE 3-6[91]

UNIT WEIGHT OF SEDIMENT IN SEDIMENT VOLUME COMPUTATIONS

TYPE OF RESERVOIR OPERATION	INITIAL WEIGHTS (Lara and Pemberton) W_1			K FACTORS (Lane and Koelzer) K		
	Clay	Silt	Sand	Clay	Silt	Sand
I. Sediment always submerged or nearly submerged	417	1,121	1,554	253.2	91.5	0
II. Normally moderate to considerable reservoir drawdown	562	1,138	1,554	134.5	28.9	0
III. Reservoir normally empty	642	1,152	1,554	0	0	0
IV. River bed sediments	963	1,170	1,554	0	0	0

Unit Weights after various Units of Time

$$W_{\text{ave time }(T)} = W_1 + .4343K\left[\frac{T}{T-1}\left(\log_e T\right) - 1\right]$$

$W_{10} = W_1 + .675K$ $\quad$ $W_{60} = W_1 + 1.372K$

$W_{20} = W_1 + .938K$ $\quad$ $W_{70} = W_1 + 1.438K$

$W_{30} = W_1 + 1.093K$ $\quad$ $W_{80} = W_1 + 1.493K$

$W_{40} = W_1 + 1.210K$ $\quad$ $W_{90} = W_1 + 1.542K$

$W_{50} = W_1 + 1.298K$ $\quad$ $W_{100} = W_1 + 1.588K$

Sample Computations

Size Analysis:

Clay = 23%

Silt = 40%

Sand = 37%

100 Year Sediment Storage

Compute K

$K = 34.5\ (0.23) + 28.9\ (0.40) + 0$

$K = 31.0 + 11.55 = 42.55$

Reservoir Operation: Type II

Compute W_1

$W_1 = 562\ (0.23) + 1{,}138\ (0.40) + 1{,}555\ (0.37$

$W_1 = 129 + 455 + 575 = 1{,}159\ \text{kg/m}^3$

$W_{100} = W_1 + 1.588\ K$

$W_{100} = 1{,}159 + 1.588\ (42.55)$

$W_{100} = 1{,}159 + 67.7 = 1{,}227\ \text{kg/m}^3$

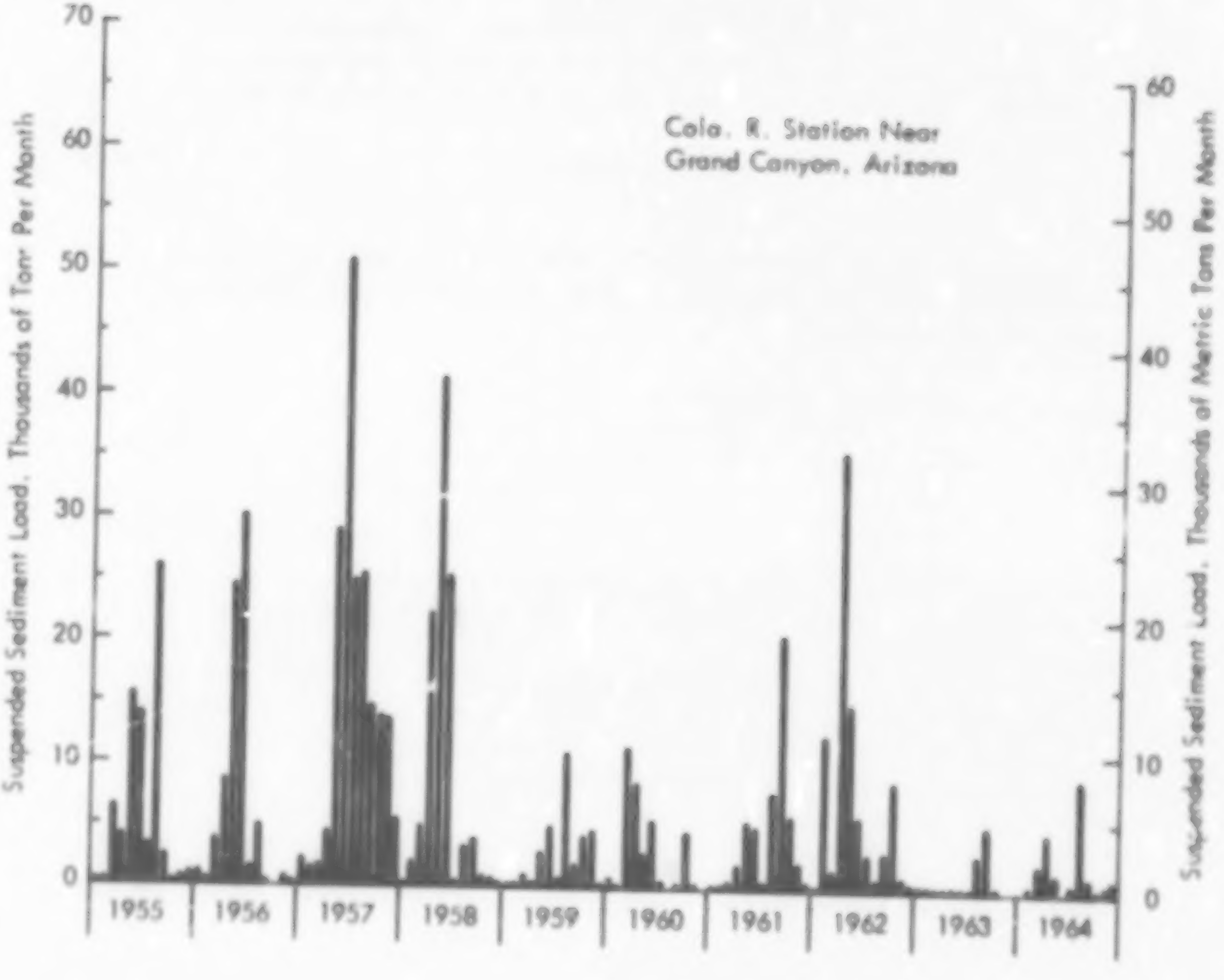


Figure 3-15 - Sediment Load Variations in Lake Mead During 1955-64[58]

3.5.3 Site survey and verification techniques: In order to make reasonable estimates of the nature and extent of pollution from agricultural sources, the engineer/planner may pursue two methods of inquiry.

(a) Materials balance method: This method involves preparation of input-output tables on specific pollutant sources such as nutrients and pesticides, and their rates of reaction in the aquatic environment. Thus, the nutrient budget for a given watershed can be written as:

$$\text{output} = \text{input} - \text{storage} \quad . \qquad (3\text{-}15)$$

Each term in the above expression may involve several sources. For agricultural runoff from a farmland in a given watershed, the following expression can be evaluated:[73]

$$\begin{aligned}\text{Runoff} = f \Big[&(\text{fertilizers} + \text{animal manure} + \text{precipitation} \\ &+ \text{advection} + \text{minerals dissolved} + \text{biological} \\ &\text{transformations}) - (\text{storage} + \text{harvest removal} \\ &\text{of crops} + \text{atmospheric transfer}) \Big] \quad . \end{aligned} \qquad (3\text{-}16)$$

Many of these terms are difficult to measure or estimate as different rates and different forms of nutrients in the runoff affect the data.

(b) Measurement and analysis method: With statistically valid samples obtained in a systematic water quality monitoring program, one can establish relationships between any two or three factors such as BOD vs. number of cattle, drainage area vs. sediment load, phosphorus vs. sediment flow, and pesticide vs. runoff, for any watershed and for each land use. When a man-made disturbance is suspected to be a cause of water pollution, sampling and analysis of stream water and sediment can identify the nature and extent of the disturbance and help to pinpoint the location of the source.

The monitoring program must be carefully designed to insure that necessary information of good quality is obtained without undue expense. The boundaries of the drainage area must be defined before the study. Sampling sites must be chosen based on land use and geographic features such that the best estimate of the average reflects the majority of the features. Both surface and subsurface water drainage should be sampled and analyzed for pollutants. The analytical procedures can be established rapidly with some experience so that nonsignificant pollutants are not routinely analyzed.

The location of sampling sites, and their distance from the source will affect the accuracy of the stream monitoring data. Other factors which must be considered include antecedent rainfall, basin geometry, nature of intervening discharges, and chemical and physical reaction rates.

Base line data will help establish the degree of man-induced disturbance at a point upstream of the sampling site. Stream flow records are kept on most streams by the U.S. Geological Survey, based on routine monitoring of these streams. EPA and USGS maintain computerized stream water quality data on most streams. USDA, through its Agricultural Research Service and Soil Conservation Service also maintains stream surveillance records. The Corps of Engineers and the Bureau of Reclamation likewise maintain extensive sampling and analysis data on streams, lakes, and reservoirs. In the absence of such data on a small watershed for which water quality is evaluated, on-site sampling will provide the required information.

While water quality monitoring is essential in evaluation of pollution from nonpoint sources, stream monitoring methods have inherent limitations. The selection of sampling sites may be limited by available resources, which in turn will reflect the quality of data collected. The monitoring of water quality in a watershed containing a large number of pollution sources of similar nature may confuse the origin of pollutants unless the runoff from each source is monitored. The distance from a source to the point of discharge into a stream will influence the quantity of pollutant entering the stream. Variations of distances from similar sources will complicate the accuracy of predictions. Finally, the interactions of the pollutants as they travel through the watershed may alter the pollutant species to such an extent that identification of their origin may be difficult.

3.5.4 Stream sampling techniques for prediction:

Location of sampling sites: Where conditions permit at least two sites must be selected, one upstream and one downstream of the potential source suspected of contributing nonpoint pollution. These sites must be as close as possible to preclude contributions from other potential sources.

Parameters to be monitored: Only those parameters which are most likely to contribute to the evaluation of agricultural pollution should be monitored. These parameters may include flow rate, pH, temperature, turbidity, suspended sediment, dissolved oxygen, chemical oxygen demand, phosphorus, nitrogen, coliform MPN, and specific conductance. Other important parameters which should be selectively monitored include pesticides, salinity measurements, biochemical oxygen demand, and fecal coliforms.

Frequency and duration of sampling: Since the runoff rate and concentration of dissolved and suspended materials vary during any given runoff period, samples are required periodically throughout the runoff period. Because the greatest changes in rates of runoff and transported materials occur during the rising stages of the hydrograph, samples must be collected more frequently during this period than on the recession side (Figure 3-16). Thus, the sampling equipment must be capable of collecting individual samples at predetermined time intervals throughout the runoff hydrograph.[45] Operating procedures and other design features of the system are contained in the USDA publication ARS 41-136, which should be consulted for further details.[45]

Recently, Dissmeyer[17] has proposed a method of estimating the impact of different land use practices on stream water quality. Although his method is applicable to forest land and aims specifically at sediment yields in watersheds, the general principles of the method may be extended to farmland pollution of sediments. A detailed discussion of Dissmeyer's method is presented in Section 4, "Silviculture," of this report. It must be recognized, however, that relating other pollutants such as nutrients and pesticides to specific sources remains to be demonstrated in this method.

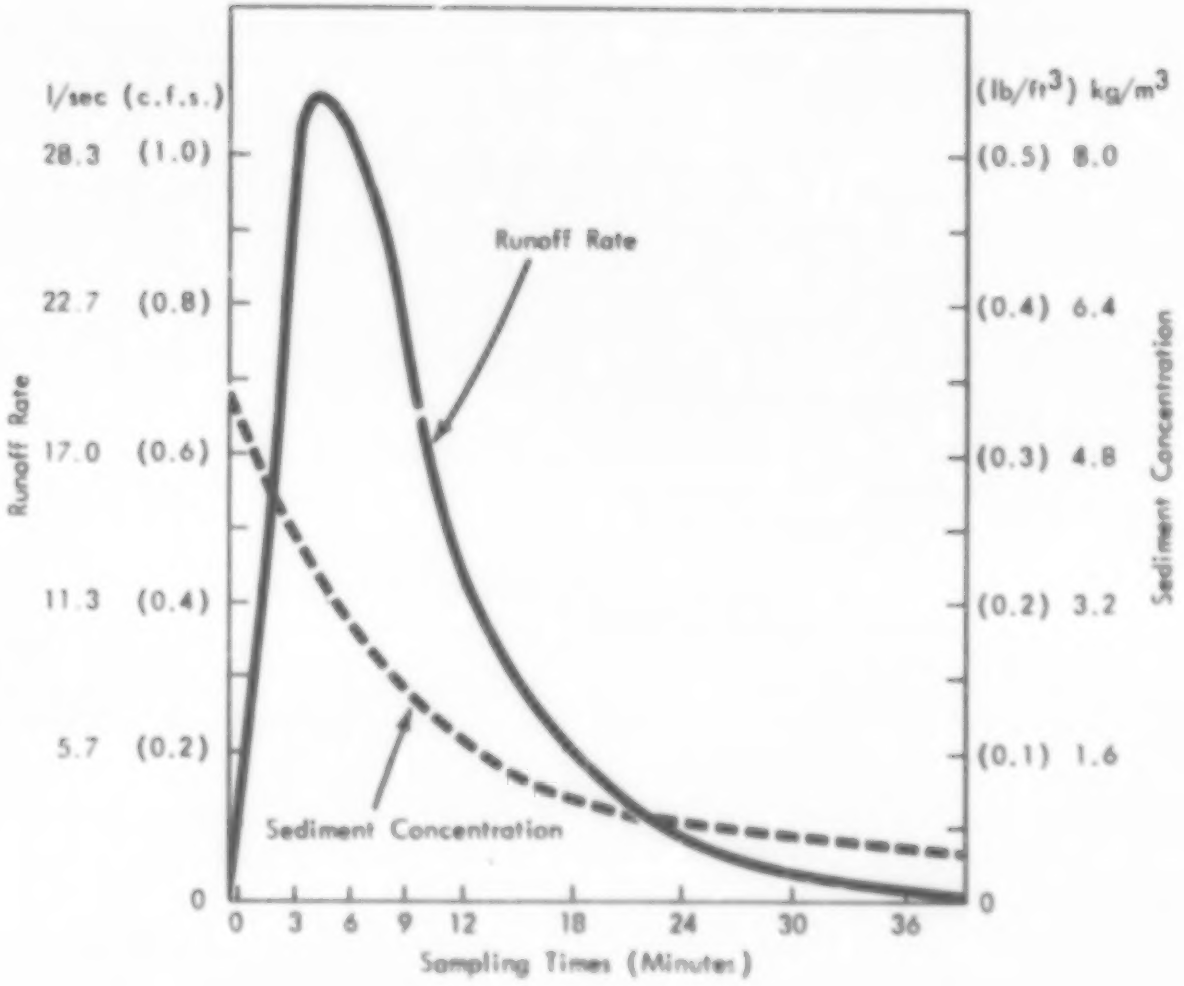


Figure 3-16 - Simplified Runoff Hydrograph and Sediment Load from Small Agricultural Watersheds 43/

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4.0 SILVICULTURE

4.1 Introduction

The gross area of the 50 states of the U.S. is about 916 million hectares (2,264 million acres). Over one-third of this is covered with forests. Approximately 67% of the forests are classified as commercial forests, totaling 203 million hectares (500 million acres), of which approximately 27 million hectares (67 million acres) are in private industrial ownership, 41 million hectares (100 million acres) in public ownership, and the rest in private, nonindustrial ownerships. Depending on natural and land use characteristics, these lands may produce substantial quantities of pollutants to surface and underground waters.

An established, well managed forest can be remarkably resistant to emission of pollutants to the aquatic environment. Incident rainfall is deprived of most of its erosive force by the tree cover, and rates of infiltration through ground cover and into subsurface soils are often high enough that intense rainfall can be accommodated without runoff and the accompanying carry-off of silt by erosion. Such a forest has the attributes popularly decreed to be necessary and desirable, as well as technically and economically sound. Many forests do indeed possess such attributes, and are at the same time useful, productive entities. Productivity can be maintained over the long term with assistance from man, which necessarily includes harvest of trees. A silvicultural cycle includes a relatively long period of growth which can be essentially free of pollutional output, and a relatively short period of harvest and reforestation, which, as a result of disturbances, can be a time of high pollutional output.

Disturbances to the forest come from nature as well as from man. Disease, insects, windstorms, droughts, and fires can devastate a forest, and degrade it to a polluting condition. Silvicultural activities, which are generally concerned with timber production, with prevention of natural devastation, and with restoration to a state of health and productivity, consist of harvesting, reforestation, growth promotion, disease prevention, fire fighting and fire prevention.

The principal sources of pollution from forests thus are disturbances which are natural in origin or are caused by man. The major types of pollutants from forestlands are sediment, organic matter, applied forest chemicals (pesticides, fertilizers, fire retardants), plant nutrients,

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and pathogens. Thermal effects on streams from solar radiation associated with the reduction of shade from streamside vegetation are, in some cases, pollutional.

This section summarizes findings relative to the identification and evaluation of pollution from forestlands. The section initially gives a review of silvicultural practices, both those now in use and potentially future processes; and proceeds to enumeration of specific sources and practices which effect pollution of water. The characteristics of practices and sources pertinent to their impact on the aquatic environment are presented in terms of major types of pollutants, and how these pollutants move from the forest to surface and groundwater, how natural and operational factors affect relationships between inputs from the sources and pollution levels in waters, and in some cases, to what extent the pollutants have deteriorated water quality. Finally, a procedure for quantification of pollution from silvicultural activities is presented in terms of estimation methods, and a general approach to sampling and monitoring of water quality.

4.2 Silvicultural Activities

4.2.1 Overview: Silviculture is defined as the theory and practice of controlling forest establishment, composition, and growth.[39/] It is a continuous management process that begins when mature timber is harvested and the site is prepared for a new crop of trees. Depending on the region, type of species, topography, and method of regeneration, etc., the forester might be required to burn excess slash, disc the site, or use some other technique to prepare the area for reforestation and a new crop of trees.

As the forest begins to develop, overstocking might be a problem. In that case, a precommercial thinning may be necessary to remove poorer quality growth and provide growing space for the best stems. On the other hand, understocking might require planting open spaces to assure full utilization of the site. Later, as the stand begins to reach merchantable size, a thinning might be made to remove products such as poles, pilings, pulpwood, and fence posts. The main purpose of thinning, however, is to provide growing space for the best quality trees.

As the forest grows, a forester will provide protection and maintenance to the timber stands. This may come in the form of insect spraying, prescribed burning, application of fire retardants, and other physical or biological techniques that will assure that the stand will be available for harvest at the end of the rotation.

In forest management, the appropriate silvicultural system is selected which will assure optimal productivity of desirable tree species. A harvest system to achieve these objectives is then selected and implemented. A primary log transport (yarding) method is used to remove logs from the felling location to a landing or transfer point. The method should be economical, minimize damage to the site and provide site conditions compatible with species restocking requirements. Each stand must be tied to a series of roads so that a balanced, long-range management program can be achieved.

4.2.2 Harvesting systems: The harvesting methods recognized by the forestry profession in the United States are the clearcut, seed-tree, shelterwood, and selection systems.[91/] These methods are based on ecological and economic considerations for the desired tree species.

The ecological factors that are considered in the selection of a harvest method include the silvical requirements of the favored timber species, the relationship between the forest and wildlife, potential insect and disease problems, the impacts of fire and climatic hazards, the vigor of the timber stand, and the potential for using artificial reproduction methods.

Economic factors are also weighed in the selection of a harvest system. These include the availability of markets, management and harvesting costs, value of the product, and future costs of protection and maintenance. Each of the harvesting methods are discussed in the following sections.

(a) Clearcutting: This is a method whereby virtually all trees are removed in the harvesting process. It lays bare an area for the establishment of a new even-aged forest. Clearcutting is particularly adapted to subclimax species that do not reproduce well under low light intensity and strong competition for soil moisture. It is also adaptive to the prompt establishment of genetically improved stands through artificial reforestation. The principal species that are harvested by clearcutting are shortleaf pine and loblolly pine in the South; red pine and jack pine in the Lake States; red spruce, white spruce, and balsam fir in the Northeast; lodgepole pine in the Rocky Mountains; and Douglas fir in the Pacific Northwest.

Clearcutting may range in size from a few acres to many hundreds of acres. It may be done in strips, patches, or over entire watersheds. If not properly planned and executed, clearcutting may lead to serious water pollution problems by the acceleration of sediment production.

(b) Seed tree: Harvest by this system removes all trees on an area with the exception of a few of the most desirable trees that are left to produce seed and restock the cutover area. When sufficient reproduction is established, the seed trees are then harvested. The method is especially adapted to light-seeded species that require minimum competition and bare mineral soil for establishment. The seed tree method is used to harvest the longleaf, loblolly, slash, and shortleaf pine types in the South. Next to clearcutting, the seed-tree method probably has the highest potential of releasing sediment into streams.

(c) Shelterwood: Application of this method, which currently has very limited application, involves gradual removal of an entire stand in a series of partial cuttings extending over a fraction of the rotation. Under intensive forest management, these cuttings resemble heavy thinnings. The main difference between the shelterwood system and the two previously discussed methods is that establishment of a new crop is accomplished before the final harvest removal. This system is used on flatter ground where track or wheel yarding tractors can operate easily. The system may require a great amount of skid trails and roads. Heavy-seeded and intermediately tolerant species are well adapted to the shelterwood harvest system. The following forest types may be harvested by this method: the Appalachian hardwoods, the Central hardwoods, and Eastern white pine and red pine types in the Lakes States.

(d) Selection: The selection system is applicable only where it is desirable to maintain an all-aged forest. The oldest or largest trees are removed at periodic intervals of 5 to 20 years. Any one harvest would normally remove less than one-third of the total stand. The selection system is adapted to tree species that are tolerant and will reproduce under dense shade and competition for moisture and nutrients. The system is normally restricted to flatter ground where track or wheel vehicles can operate. On steep ground the system requires a higher intensity of skid trails and roads than other systems.

4.2.3 Log transport methods: After trees are felled in a logging operation, they are collected into a yarding area where they are loaded into trucks. The logs are then transported to the mill via permanent roads. In a few cases in New England and the West, logs are rafted from yarding areas to the mill on streams or rivers. For the purpose of this report transport is defined as the movement of logs from the point of felling to a permanent road. This is usually described in logging terminology as skidding, yarding, or snaking operations. This section identifies the pollution potential of the following methods of log transport: tractor, high lead, skyline cable, balloon and helicopter.

(a) Tractor: Tractor skidding can be done with either four-wheeled tractors or crawler tractors. A winch may be used to snake logs to the tractor before skidding them to the yarding area. Two improvements are often used to minimize scarification of the site--a skid pan and a high-wheeled arch yarder.

Tractor skidding is the most common method used in the Northeast and South, and on lands with less than 30% slope in the Intermountain, Northwestern and California regions. Even on level to rolling land, however, tractors can expose more bare soil than other methods of log transport.

(b) High lead: The high lead log transport system is adapted especially to clearcutting. A metal tower about 23 meters (75 ft) high is mounted on a mobile frame. Guy lines hold the tower in place, and a winch and set of cables at the tower drag the logs along the ground to a yarding area, where they are loaded into a truck. The pollution potential is generally less than for tractor skidding, although when logs are repeatedly yarded over a high spot on the ground, profile deep cuts into the soil may occur.

(c) Skyline cable: This method employs a cable to carry the full weight of the logs as they are transported. Aerial cables are attached to the towers which are constructed at the opposite ends of the logging sites, and logs are mechanically lifted off the ground and moved along the cable to the landing area. The landing area is usually near the base of one of the towers. Logs may be moved to the top or to the bottom of a drainage slope in order to yard logs near a permanent road.

Since a large volume of timber is required to justify this type of setup, the method is used principally on clearcut logging operations. There is less potential for pollution from this method because fewer temporary logging roads are usually required. Herman reported that skyline cable logging requires only one-tenth as much road construction as more conventional methods such as tractor and high lead.[43] Logs are also lifted off the ground, thereby avoiding cuts on the forest floor.

The system can operate at distances of more than 900 m (3,000 ft). Cables should be installed at a height that will insure that logs are lifted off of the ground during most of the transport operation. Soil disturbance is then confined to yarding and loading areas.

(d) Balloon: This method employs a large balloon usually filled with helium and capable of static lifts of 4.5-9 metric tons (5-10 tons). A cable system similar to high lead is used to control the horizontal movement of the balloon over the logging site. A snubbing line may be required to winch the unloaded balloon close to the ground. The static and dynamic lifting forces hold the logs off the ground during yarding. Balloon logging is adapted to steep slopes (45 to 90%) where clearcutting is used on unstable soils. A minimum of 70 m^3 per hectare (12,000 board-feet per acre) is necessary to justify this type of log transport.[30]

Balloon logging causes soil disturbance and erosion only at the landing areas where the logs are loaded into trucks. Landing or yarding areas can be as far as 900 m (3,000 ft) apart. Balloon logging is more expensive than most other logging systems.

(e) Helicopter: Using a helicopter, logs are lifted from the ground at the point of felling and transported to the loading area. Binkley[5] found, in studies in the Pacific Northwest, that helicopter logging required fewer access roads, was more expensive (direct variable cost) than other methods, and that it was a very versatile system for moving logs from felling sites to loading areas. Binkley suggested that helicopter logging be used to transport valuable timber in inaccessible areas where managing for aesthetic values has high priority.

4.2.4 Regeneration: The regeneration process differs substantially for different regions and types of forests, and the harvesting method is usually geared to favor propagation of desired tree species. Several types of regeneration methods are discussed briefly in the following subsections.

(a) Tree planting: Tree planting on clearcut areas, understocked areas, and burned areas, is an increasingly common practice. Numerous governmental agencies and the private forest industry have led in this activity. Scientific guidance is available to enable the establishment of productive forests in marginal areas as well as areas suitable for high yield timber production. Since 1930, 14.7 million hectares (36.3 million acres) of land in the U.S. have been planted with trees.

(b) Natural regeneration: Natural regeneration to establish productive stands of preferred tree species is best obtained when the forest practice is set up to provide favorable conditions for natural germination and growth of desired seedlings. The method of harvest is an important factor in establishing the required conditions. The seed-tree method is suitable for propagation of selected southern pine species. The shelterwood system of harvest is well adapted to regeneration of Appalachian mixed hardwoods. The selection system is adapted to propagation of species such as Engelmann spruce and alpine fir in the Rocky Mountains and ponderosa pine in the West. The clearcut harvest method is suitable for establishment of uniform stands (even-growth) of intolerant species that do not reproduce readily under competition from other trees: southern pines, Douglas fir in the Pacific Northwest, and western white pine in northern Idaho are among the classic species which achieve satisfactory reproduction from clearcut areas.

(c) Influence of fire on regeneration: Forest wildfires have historically played an important role in natural regeneration and maintenance of preferred tree species. Hendrickson[42/] has stated that from studies of tree rings, the frequency of fires in various types of forests are shown in Table 4-1.

TABLE 4-1

FREQUENCY OF FOREST FIRES NECESSARY TO MAINTAIN SPECIES FOR UNMANAGED FORESTS[42/]

Tree Species Requiring Fire to Maintain Themselves in a Forest	Frequency of Fires (years)
Slash pine, longleaf pine	3-18
Ponderosa pine, pitch pine	12-25
Douglas fir	25-50
Quaking aspen	50-100
Lodgepole pine, jack pine	100-300

As the art of silviculture has advanced, the use of fire has been beneficially applied, and in recent years use of prescribed fires in silvicultural activities is a scientifically accepted practice. Prescribed burning is extensively employed in some areas to reduce potential wildfires by systematically preventing the surface buildup of fuel resulting from slash and other forest debris. Traditionally it has been an accepted silvicultural practice to remove surface vegetation by a process of controlled burning to permit direct contact of seed from intolerant tree species with mineral soil.

4.2.5 Intermediate practices: Certain practices are employed primarily for the benefit of the growing forest. Chemical pesticides are used for control of insects, weeds and weed trees, plant diseases and rodents. The application of chemical fertilizers has been a new practice for increasing unit growth increments. The use of fire retardants to control or manage fire is an essential practice in silviculture. Prescribed burning may also be an intermediate practice.

4.3 Nature and Extent of Sources of Pollution from Silvicultural Activities

4.3.1 Overview: Pollutants from silvicultural activities are similar to those generated by agriculture. The most important pollutant originating from silvicultural activities is sediment. Sediment is eroded and transported to surface waters by the action of runoff and rainwater. Excessive quantities of sediments degrade water quality physically, chemically and biologically. Sediments are carriers of pesticide residues and nutrient elements, and are significant pollutants for this reason.

Thermal pollution from solar radiation can be a result of silvicultural activities. Although deviations from "normal" temperatures in surface waters are considered pollutional, thermal pollution involves only the elevation of temperature above a norm. Thermal pollution in forests results from the removal of tree cover which protects streams from solar energy. Surface water temperatures may become substantially higher when exposed to direct sunlight.

Organic matter of vegetative and animal origin is likewise transported to surface waters by runoff. The organic matter ranges from green vegetative refuse through well-decomposed humic matter. The organic matter sometimes has a high nuisance value (floating debris); sometimes physically interferes with normal aquatic ecology (bark deposited in spawning beds); and nearly always becomes involved in biochemical processes which are nature's way of degrading organic matter, and which can markedly alter chemical/biological balances in an aqueous ecosystem.

Pesticides used in silviculture are potential water pollutants. Insecticides, fungicides, herbicides (silvicides) and rodenticides used to protect forests may be deposited directly in surface water courses by careless application, or be transported thereto in surface runoff. Pesticides differ from other pollutants in that the great majority of pesticides used in silviculture are not materials native to the forest environment. Pesticides, furthermore, are toxic, by design, to some part of the environment in the accepted mode of use. Evaluation of pesticide pollution is a more complex issue than the evaluation of other forest pollutants. Analyses of the pollution potential require a knowledge of: persistence of the pesticide at the point of use; rates of degradation; modes of degradation and identities of biological and chemical metabolites; mechanisms of transport through the environment to nontarget species for those pesticides that are not biodegradable; and knowledge of toxicity to nontarget species.

Fertilizers and fire retardants contribute nutrient elements to the forest environment. These elements, primarily nitrogen and phosphorus, can be transported overland to surface waters in runoff and to both surface and groundwaters by infiltration through ground cover and subsurface soils and mineral formations. In addition to the contributions from fertilizer and fire retardant application, nitrogen, phosphorus, and other nutrients can also be added to streams from the cutting and burning of forests--because these activities interrupt the natural nutrient cycling of the forest ecosystem. Among these nutrients, nitrogen is a "water soluble" element in both the reduced (ammonia) and oxidized (nitrate) forms, and is much more susceptible to transport in runoff water and infiltrating water than is phosphorus. Ammonia is toxic to fish at the part per million concentration range. The nitrate ion is toxic under certain conditions. Phosphorus is chiefly noted for its accelerating role in eutrophication processes. Both nitrogen and phosphorus are highly essential elements present naturally in abundance--they become pollutants when their presence causes adverse effects on the aquatic environment.

Bacteriological pollution of surface water from forestlands can originate from soil, plant and tree debris, and, most importantly, animal and human wastes. Pathogenic agents emitted from these sources may subsequently infect animals, or in case of some disease producing agents, humans.

4.3.2 Sediment: Sediment is produced from erosion of soils. Three major erosion processes are of concern in forestlands: surface erosion, mass soil movement, and channel erosion. Surface erosion is the direct result of rain striking unprotected soil surfaces, detaching soil particles, and transporting them by overland flow across the soil surface. Mass soil movement is the process by which large volumes of soil and rock materials move downslope under the influence of gravity. Channel erosion is the result of abrasion by water or debris on stream bank and stream bed.

Silvicultural activities may accelerate soil sediment production through influencing all three processes: surface erosion, mass soil movement, and channel erosion. This subject has been reviewed in detail by Brown.[9]

(a) Surface erosion: Surface erosion in forestlands is affected by the following natural and man-caused factors:[9] road construction, logging, fire, and grazing. These factors conbribute to soil erosion by exposing surface soil to the erosive effects of rainfall and runoff.

The impact of raindrops causes the detachment of soil which is unprotected by vegetation or litter. Soil detachment is the principal effect of the transfer of kinetic energy from raindrops to soil mass. The detaching ability of rainfall depends on raindrop size and velocity and on rainfall intensity. It has been estimated that rainfall of 5 cm (2 in.) an hour generates 458 kw/hectare (250 hp/acre), enough to lift 18 cm (7 in.) topsoil layer to a height of 0.92 m (3 ft) about 86 times.[72]

Surface erosion results when precipitation exceeds the infiltration capacity of forest floor materials and underlying soils. When soil particles are exposed by raindrops, they are subject to detachment and the structure of the soil is altered. Large pore characteristics of many forest soils become clogged, thus sealing the surface and reducing the infiltration rates, which are normally high. Rainfall which should have infiltrated now becomes runoff and overland flow.

Mechanical compaction of surface soil by machines or animals also may reduce infiltration and produce surface runoff. When combined with vegetation removal, mechanical compaction may result in extremely high erosion rates on certain soils and slopes for a short period of time.

Physiographic factors of surface soil may influence soil erosion directly or indirectly. Steepness of slope and length of slope directly influence erosion through their influence on the velocity of surface runoff. Since velocity increases with the square root of slope, and the sediment-carrying ability of water increases with the sixth power of the velocity, one might expect the sediment-carrying potential of surface runoff to increase with the cube of the slope. Elevation and aspect affect soil erodibility indirectly through their influence on soil development. Willen[94] compared the erodibility of granodiorite soils at elevations over 2,160 m (7,000 ft) with similar soils at elevations of 600 m (2,000 ft). He found that the high elevation soils were potentially 2.5 times more erodible. A similar relationship might be expected where aspect limits soil development.

As soil development proceeds, a larger proportion of surface soil particles are combined into water stable aggregates. Thus, those factors which influence soil development should influence structural stability and aggregate size and thereby the resistance of soil to erosion by water. Major factors which influence soil development are discussed below.

- Parent material: Many forest soils are shallow, immature and therefore poorly developed. Their characteristics are often closely related to the parent rock. In the West, several types of rock give rise to highly erodible soils. Among these are the acid igneous rocks, such as granite and granodiorite. The degree of aggregation and the aggregate stability of soils derived from these parent materials are quite low. Flocculation and dispersion of soil colloids are related to the absorbed cations present in the soil. The cations, in turn, are derived from the weathering of parent rock. The parent rock, therefore, also determines the nature of the chemical bonding within the soil matrix. The low fertility of these soils generally results in low plant density and a lower organic matter content of the soil.

- Climate: Climate, particularly moisture and temperature, strongly influence the rate and extent of soil development. Temperate, moist sites favor rapid breakdown of parent materials and consequent soil development. Wetting and drying cycles, as well as freezing and thawing, influence aggregate development by accentuating lines of shear within the soil and by mixing soil particles.

- Biologic activity: Biologic activity favors soil development and resistance to erosion. Earthworms and plant roots mix and disrupt the soil matrix. Acidic by-products of microbial decomposition and leachate from plant litter help decompose parent materials. Organic materials act as an important cementing agent in the formation of aggregates from primary soil particles. Organic matter may also influence aggregation by an electrochemical bonding in much the same manner that clay minerals interact. Generally, the higher the organic matter content, the larger the aggregate size, and the less erodible the soil.[22]

- Time: Time is required for soils to develop from the parent rock. The absolute rate is a function of climate, parent material, living organisms, and topography. The relative degree of development, however, is related to the time since the soil forming process began. Thus, soils formed on newly-deposited pumice or lava would probably be less well developed than soils developing on ancient lava flows.

- Physiography: Physiography influences soil development in several ways. One of the principal ways is through its influence on microclimate. Slope, aspect, and elevation modify the radiation, temperature, and moisture levels of the general climate. As a result, weathering of parent material and composition of plant communities may also be modified.

Construction of roads, skid lanes, and fire lanes, harvesting, fire, and grazing in forestlands may contribute to soil erosion by exposing surface soil to the erosive effects of rainfall and runoff.

(i) Skid lanes and fire lanes: Roads are conceded to be one of the principal sources of soil sediments from forestlands. Logging roads ordinarily are constructed prior to the logging operation. They provide access for equipment, and serve as routes for transport of logs out of the forest. Skid trails are the disturbances created by hauling logs from the freshly cut area to yarding areas or roads. Fire lanes are established, either permanently or temporarily, but cutting stands to prevent expansion of forest fires.

The mineral soil surfaces of logging roads, skid trails, and fire lanes, are exposed and compacted, and have little capacity to absorb runoff during storm events. Such runoff not only causes erosion on the road surface, but also initiates erosion in less disturbed areas.

Forest roads that are improperly designed and constructed are often the main cause of high sediment content in streams flowing through forested watersheds.

The effect of road construction on the extent of soil erosion and sediment production is dependent on numerous natural factors and man's activities involved. In the following paragraphs, results are presented from specific research experiments in various parts of the United States. Because of the complexity of the subject, no generalization can be made from the relatively small number of experimental studies.

In central Idaho, Megahan and Kidd[61/] reported that sediment production in streams primarily resulted from the construction of logging roads, and that nearly 84% of all sediment was produced during the first year after construction. An additional 9% was generated during the second year, and about 2% or less each year for the next 4 years.

At Castle Creek in California, Rice,[80/] and Anderson and Wallis[3/] showed that sediment resulting from construction of roads in a 10 km^2 (4 $mile^2$) watershed increased the average sediment concentration and sediment yield by fivefold in the first year: from 64 ppm to 303 ppm, and from 326 metric tons/km^2/year (935 tons/$mile^2$/year) to 1,610 metric tons/km^2/year (4,600 tons/$mile^2$/year). In the second year, concentrations and yields declined to twice the normal rate.

Properly planned and managed road construction will result in greatly reduced erosion. A study in West Virginia by Reinhart[78/] showed that a well planned logging operation produced a maximum turbidity of 25 JTU (Jackson Turbidity Unit), while in an adjacent watershed, tractor-logged without plan or direction, maximum turbidities of 56,000 JTU were recorded.

In Alaska, sediments may result from fire lanes constructed in areas of low relief if the soil is fine textured. Bolstad[6/] has indicated that when the organic protective covering is removed, the shallow permafrost melts, and surface water starts to flow downward and laterally, to cause surface soils nearby to collapse. Silts and clays then move through ice caverns to accelerate the process of erosion and soil sediment deposition in nearby streams.

(ii) Harvesting: Disturbed forest litter and exposed soil resulting from harvesting and logging are the principal sources of sediments in a harvested area. The harvested area is susceptible to erosion until new vegetative cover is established. Harvesting in combination with log transport may result in varying degrees of damage to the forest floor. Rice, et al.,[79] who reported data (Table 4-2) on effects of log transport and harvesting systems, found that clearcutting by the balloon system of logging resulted in the lowest soil sediment load deposited in the streams. Using this method only 6% of the logged area was made bare to mineral soil. In contrast, clearcutting by tractor laid bare 29.4% of the logged area.

TABLE 4-2

PERCENTAGE OF SOIL IN LOGGED AREA MADE BARE BY VARIOUS LOGGING SYSTEMS IN WASHINGTON AND OREGON [79]

Portion of State(s)	Logging System	Percentage of Soil in Logged Area Made Bare
Eastern Washington	Tractor (clearcut)	29.4
Western Washington	Tractor (clearcut)	26.1
Eastern Washington and Oregon	Cable (selection)	20.9
Eastern Washington and Oregon	Tractor (selection)	15.5
Western Oregon	High lead (clearcut)	14.1
Western Oregon	High lead (clearcut)	12.1
Western Oregon	Skyline (clearcut)	12.1
Eastern Washington	Skyline (clearcut)	11.1
Western Oregon	Skyline (clearcut)	6.4
Western Oregon	Balloon (clearcut)	6.0

Results of field studies seem to indicate that clearcutting itself may be less damaging than the roads necessary for access to the logging site. In studies where trees were clearcut and left in place, no increases in sediment occurred during the first year, but stream flow increased 65%.[51]

Likens, et al.,[52] also reported no increase in turbidity following clearcutting on a New Hampshire watershed. In this study trees were not removed from the watershed, but remained on the ground.

In the Northwest area, Brown and Krygier[13] studied a clearcut by high-lead system in a 15 hectare (39 acre) watershed and reported that no measurable increase in suspended sediment was observed. Fredricksen[29] reported that on a watershed clearcut over a 3-year period with a skyline system, sediment concentrations were only modestly affected. Mean concentration during storms remained below 10 ppm.

Lynch,et al.,[56] conducted a watershed study in Pennsylvania. The watershed was clearcut and logged carefully with little disturbance of the soil surface. Suspended sediments were measured throughout 4 years after treatment on the clearcut and uncut forests. During the first year, the mean concentration was 6 times greater (16.5 ppm compared to 2.7 ppm) and the maximum 14 times greater (72 ppm to 5.3 ppm) on the clearcut than on the uncut forest. These differences in concentration became negligible during the next 4 years.

Eschner and Larmoyeux[25] demonstrated that in West Virginia there was a direct and positive relationship among the harvesting method, the percentage of harvested area in bulldozed roads, and the maximum stream turbidity. Turbidities of streams varied from 15 JTU for areas not logged and where no roads had been built, to 56,000 JTU under clearcut regions where 3.6% of the area logged was in roads.

(iii) Fire: Fire in forests may subsequently accelerate soil erosion: (1) fire consumes vegetation, litter and duff materials, and leaves soils unprotected against the impact of raindrops and runoff; (2) removal of soil surface protection reduces evapotranspiration and increases water available for surface erosion; (3) hot fires may reduce the organic content of soil and alter the stability of surface soil aggregates; (4) hot fires may reduce infiltration rates and increase surface runoff on many soils by production of a non-wettable surface layer. All these elements increase the susceptibility of soil to water erosion after forest burning.

Prescribed burning has been used, especially in the South, by silviculturists since the turn of the century. This practice is used: (1) to reduce the fuel accumulation, and therefore, the hazard of very hot and uncontrollable wildfires; (2) to control undesirable species of trees such as oaks in an oak-pine forest; (3) to improve the habitat for wildlife; (4) to prepare a seedbed for natural reseeding and for planting of pines; (5) to enhance grazing; (6) to control the brown spot fungus disease of longleaf pine; (7) to increase volume growth of trees.

The effect of forest fire on soil erosion varies with factors such as soil type, rainfall pattern, and topography. For each case, evaluation of such effects should be based on the specific factors involved.

Ralston and Hatchell75/ have reported on comparative soil erosion losses from burned and unburned forests in the South. In five locations studied, soil erosion was greater in the areas treated by prescribed burning, by factors ranging from 7 to 1,500.

Brown and Krygier13/ reported a large increase in sediment yield after a very hot slash fire in a 70 hectare (175 acre) clearcut watershed in Oregon. Sediment yield increased about threefold after road building and about fivefold after logging and burning, over the value expected for the undisturbed area. Higher than normal sediment yields persisted for 3 years after logging and burning, but declined during the following years as vegetation returned.

Wildfires also leave forestlands in a state susceptible to erosion. Glascock,33/ who presented the data shown in Table 4-3 on causes of wildfires, concluded that erosion induced by uncontrolled forest fire is greater than that induced by prescribed burning.

Copeland16/ reported the effect of an extensive wildfire on sediment yields from two small experimental watersheds in Nevada. Shortly after the fire, a high intensity thunderstorm occurred for a duration of 30 min. The completely burned watershed produced about 44 m^3/hectare (630 ft^3/acre) of sediment, while another watershed, only partially burned, yielded 23 m^3/hectare (338 ft^3/acre).

TABLE 4-3

CAUSES OF WILDFIRES[33]

Cause of Wildfire	Percentage of Total
Lightning	35
Incendiary	21
Debris burning	16
Campfires	8
Miscellaneous	7
Smoking	6
Equipment use	6
Railroads	0.5
Children	0.5
Total	100.0

(iv) Grazing:[9] Overgrazing may result in serious erosion problems. Heavy grazing may lead to rapid deterioration of vegetative cover, particularly in areas with sparse vegetation, short growing seasons, shallow and poorly developed soils, and occasional drought. Under this condition, rainstorm runoff will cause severe erosion. Copeland[16] reported that thunderstorms in a summer carried 72,900 m^3/km^2 (153 acre-ft/mile^2) of sediment from a 555 hectare (1,378 acre) watershed, where vegetation was destroyed in only 12% of the area. A nearby undamaged watershed produced sediment at 1.19 m^3/km^2 (0.0025 acre-ft/mile^2).

(b) Mass soil movement: Mass soil movement is the downslope movement of a portion of the land surface under the effect of gravity. Such movements may take the form of landslide, mud flow, or downward creep of an entire hillside, and may constitute the dominant process of erosion in areas with exceptionally steep slopes, high rainfall, or low-strength soil, such as that of mountainous areas of western North America. In such areas, soil may remain in place as the result of a delicate balance between forces tending to cause downslope movement and the various forces tending to resist it. Any disturbance may upset this delicate balance and result in initiation or acceleration of mass soil movement.

The effect of mass soil movement goes far beyond increasing stream sediment yields and turbidity. When large volumes of sediment enter a small stream with a steep channel, slides may scour bed materials to the bedrock base and eliminate productive aquatic communities. When landslide materials are deposited in channels of gentler grade, they may fill pools and cover the porous gravels used as spawning sites by fish. In some instances, deposited materials may create a new bottom environment which is incapable of supporting a stable aquatic community.

Landslide is influenced by the slope of the land, composition of soil, and water content of the soil. Dyrness[23/] indicated that stony soils from basalt and andesite were 14 to 37 times more stable than those from tuffs and breccias, which are volcanic parent materials, and normally weather rapidly to silts and clays. Silts and clays can retain large quantities of water. The water adds to the soil burden and reduces its strength, thus promoting landslides. In Oregon, landslides normally occur near peak stream flow from winter storm runoff when water content of soil is at the maximum.

Silvicultural activities may play an important role in initiation and acceleration of mass soil movements. Quantitative relationships vary substantially from one situation to the next, and research observations and conclusions must therefore be interpreted with caution. Some of the research on this subject is summarized below, with the above qualification in mind.

In a review of mass erosion research in the western United States, Swanston[82/] made the following statements about the effect of disrupting activities on mass soil movements:

> "Road building stands out at the present time as the most damaging activity. Soil failures relating to this activity are the result primarily of slope loading from road fill and sidecasting, inadequate provision for slope drainage, and bank cutting.

> "Fire, natural and man-caused, is a second major contributor to accelerated soil-mass movement in some areas. This relates largely to the destruction of the natural mechanical support of soils, often abetted by surface denudation of the soil mantle, thus opening it to the effects of surface erosion.
>
> "Logging, the third activity, affects slope stability mainly through destruction of protective surface vegetation, obstruction of main drainage channels by logging debris, and the progressive loss of mechanical support on the slopes as anchoring root systems decay."

Croft and Adams[17] attributed increases in mass soil movements in the Wasatch Mountains to loss of mechanical support for root systems of trees and plants, resulting from logging and burning.

Dyrness[23] related an apparent increase in mass soil movement frequency to logging practices on the H. J. Andrew Experimental Forest, Oregon. Krammer[47] reported an increase in sediment production from mass soil movements of 10 to 16 times following a wildfire in the Gabriel Mountains of Southern California.

In the mountainous terrain of western Washington and western Oregon, where conditions favor mud slides, Fredriksen[27] reported on a mud and rock slide in a watershed in Oregon that was being monitored. Three thousand eight hundred cubic meters (5,000 cubic yards) of debris slid down 900 m (3,000 ft) of a creekbed because of a combination of a newly-built logging road, excess rain and snow, and unstable soils and geologic substrata. Mass slides tend to move downstream each season when unstable conditions exist.

(c) Channel erosion: The bank and bed of a stream are also important sources of sediment. These sources are highly sensitive to disturbances, which will directly and immediately be reflected in downstream turbidity levels.

Contributions of channel erosion to sediment discharge, in some regions of the country, can be higher than those from other sources, as indicated by two case studies. Anderson[2] estimated the following relative percentages of sediment contribution from stream bank erosion, landslide, and land surface erosion for the north coast watersheds of California:

Source of Sediment	Percentage of Total Sediment
Streambank erosion	55
Landslides (soil and debris slides)	25
Land surface erosion	20

Another comparison was made by Anderson[2] for the Willamette Basin of western Oregon on sources of sediments from stream channel erosion, forestlands, and agricultural lands, as follows:

Source of Sediment	Percentage of Total Sediment
62,600 m (205,000 ft) of eroding main stream channels	54
14,160 sq km (5,460 mile^2) of forestlands	24
4,710 sq km (1,820 mile^2) of agricultural lands	22

One of the important causes of channel erosion in the forested watershed is failure of debris jams, either natural or man-caused. When debris jams fail, they release large quantities of water together with logs, rocks and impounded sediment. The resulting torrent of debris wears channel banks, exposing new bank surfaces for erosion, and scours the stream channel.

Logging may greatly accelerate accumulation of debris. Felling may begin at the downhill cutting boundary, often a stream course, and proceed uphill. In such cases, no barrier exists to downhill movement of logging debris. The steeper the slope, the greater the probability of debris accumulation in the stream.

Meehan, et al.,[60] observed the accumulation of residues in two Alaskan watersheds under patch cutting, and compared the residue accumulation with unlogged watersheds. During 4 years, a 23% increase of debris in the stream was observed in one watershed in which about 20% of the area was logged. In the second watershed, about 25% logged, debris in the stream channel increased by 62%. During the same period of time, an unlogged watershed nearby experienced 7% increase of debris accumulation. Meehan, et al.,[60] and Helmers[40] have shown that debris jams trap sediment upstream and induce scour downstream.

4.3.3 Water temperature: Thermal effects on streams from silvicultural activities are normally the increase of temperature due to solar radiation. This is associated with the reduction of shade cover caused by clearcutting along streambanks. Such effect can cause a serious pollution problem in small streams during periods of low flow in summer months.

Temperature is a significant water quality parameter. It strongly influences dissolved oxygen concentration which affects aquatic life and bacteria population in streams. Changes of temperature can induce algae blooms, which subsequently induce changes in taste, odor, and color of a stream. Increases of water temperature may enhance the growth and development of many species of aquatic bacteria, some of which are pathogenic to fish, such as the Chondrococcus columnaris Increased populations of these bacteria may cause fish mortality.[7]

The saturated dissolved oxygen concentration is inversely proportional to water temperature. In a stream, this means that the higher the water temperature, the less dissolved oxygen is available for aquatic organisms.

In addition to the effect on dissolved oxygen and aquatic bacteria, water temperature is also a key control factor on fish growth. In some cases, fish growth rate may increase by raising water temperature. In most cases, however, lower temperatures are desired during the warm part of the year, and an elevation of temperature constitutes pollution.

Low summer stream temperature is particularly important in the Northwest, where the fingerlings of salmon and steelhead inhabit the pools of small streams during the summer months. When stream temperature becomes unfavorable, fingerlings may be isolated in these pools, and unable to migrate when water levels fall.

Research results all point to the strong effect exerted on water temperature when shade from streamside vegetation is reduced. Border strips of uncut trees, shrubs, or logging slash will shade the water and keep stream temperatures down. The nature of the effect is indicated by case studies described below.

Levno and Rothacher[50] conducted a research program on a 96 hectare (237 acre) watershed in the Cascade Range of Oregon. They reported that logging of a watershed and burning of slash increased maximum stream water temperatures above those on a watershed not logged and not burned, by 7.2°C (13°F) in June, 7.8°C (14°F) in July, and 6.7°C (12°F) in August. The maximum temperature recorded was 24°C (75°F) during a 3-hr period in July.

Using data collected over a 9-year period on the Entiat Experimental Forest in north central Washington, Helvey[41] reported that the maximum summer temperatures of recently burned watersheds were about 5.6°C (10°F) warmer than those of unburned watersheds. In winter, however, stream temperatures of burned watersheds are approximately the same as those of unburned watersheds.

Lynch, et al.,[56] calibrated a forested watershed in Pennsylvania for 7 years, then clearcut the lower one-third, and controlled new growth with an herbicide. Stream temperatures were measured for an additional 4 years. Winter temperatures were insensitive to watershed treatment, as were mean water temperature, partly because of the presence of snow and ice. Mean monthly maximum temperatures, however, were 3.3°C (6°F) higher on the clearcut area during June, July, and August.

4.3.4 Organic wastes: When materials such as tree leaves, slash, and logs get into streams, they contribute organic pollutants. Digestion of organic pollutants by microorganisms may cause dissolved oxygen deficiencies for certain species of aquatic life such as fish.[12] Organic pollutants may also cause odor, taste, and color problems.

Ponce[74] studied BOD exerted by needles of Douglas fir and western hemlock and by leaves of red alder Rates of decomposition of different materials varied. Leaves from the red alder in the Northwest, the sugar maple in the North, and the tulip tree in the South, easily decomposed and extracted oxygen from streams quite rapidly. By contrast, needles from most coniferous species were decomposed by microorganisms more slowly, and thus did not rapidly deplete oxygen in streams. Most slash and logs decomposed slowly.

The potential severity of pollution from organic wastes is illustrated by research in the northwestern United States on a harvested watershed in which dissolved oxygen dropped from 10 ppm to 1 ppm as a result of increased BOD, damming by organic debris, and stream water temperature increase caused by the direct rays of the sun shining on the surface of waters.[35]

Organic waste is also contributed by water storage of logs.[81] In the northwest United States, logging operations at higher elevation are most active between May and December due to weather conditions. However, pulp, plywood, and sawwood mills must operate year-round. Thus, logs must be stored before they are processed. Storage on dry land often induces losses by insects, diseases, and by excessive cracking due to rapid drying. To prevent these losses, logs are usually stored in private ponds, public bodies of water, or sprinkled in dry land decks. Leachates from logs stored in water increase both the chemical and biochemical oxygen demands (COD and BOD) of the water; taste and color deteriorates, and bark peeled from improperly stored logs poses a physical hazard to life in the water body.

4.3.5 Application of chemicals: Over the past quarter century, many synthetic compounds, including pesticides, fertilizers, and fire retardants have been used in forestry to realize increased forest production goals. Many of these chemicals will continue to be used, some at increased levels. These chemicals have the potential to pollute the waterways.

(a) Pesticides: In pesticide statistics, pesticide use in forestry (silviculture) is usually included in the category of industrial pesticide uses. Chemical pesticides are used in forestry for the control of insects, weeds, plant diseases, rodents, etc.

The U.S. Department of Agriculture[90] reports that forest insects and diseases are responsible for losses in the U.S. each year that far exceed the losses from forest fires. Current annual forest mortality due to insects and diseases combined is estimated at about 67 million m^3 (2.4 billion ft^3). It is estimated that insects and diseases cause an additional, equal volume of growth loss. Forest losses would be about 28 million m^3 (1.0 billion ft^3) higher if no pest control activities were carried out. The use of chemical insecticides and fungicides is credited with about two-thirds of this saving. It is anticipated that the increasing demand for timber will necessitate use of more pesticides in forestry in the future.

(i) Insecticide use: The USDA's Forest Service[89] has reported major pest control operations by federal, state and private interests. Data are summarized in Table 4-4.

TABLE 4-4

PEST CONTROL ACCOMPLISHMENTS IN THE UNITED STATES, 1969[89]

	Trees Treated	Hectares (acres) Sprayed	
Southern pine beetle: South and Southeast	439,588	-	-
Black turpentine beetle: South and Southeast	18,277	-	-
Mountain pine beetle: Idaho, Utah, Montana, Colorado, South Dakota, Wyoming	364,222	-	-
Bark beetle: California, Oregon, Washington	64,876	-	-
White pine weevil: New York	308,400	-	-
Balsam wooley aphid: North Carolina	43,000	-	-
European pine shoot moth: Washington, Oregon	11,735	-	-
Saratoga spittlebug: Wisconsin	-	54	(135)
Leafrollers and fall cankerworm: New Jersey	-	4,000	(9,836)
Spruce budworm: Idaho, Montana, Minnesota	-	9,630	(23,868)
Miscellaneous: Entire United States	1,269	-	-
Total	1,251,367	13,684	(33,839)

The U.S. Department of Agriculture[90] reports that in 1970, about 140,000 kg (310,000 lb) of insecticides and fumigants were used by the Forest Service for insect control. Pesticides used included ethylenedibromide, 106,500 kg (235,000 lb); fenitrothion, 23,100 kg (51,000 lb); carbaryl, 6,340 kg (14,000 lb); and smaller quantities of malathion, benzene hexachloride (BHC) and lindane. Two forest pests that accounted for a major part of the use of these chemical insecticides were the gypsy moth and the spruce budworm.

In the first quarter of 1971, the Forest Service planned to use insecticides on more than 280,000 hectares (700,000 acres) of forestland. On these, 152,000 hectares (375,000 acres) were slated for spraying with carbaryl to control the gypsy moth.

The Forest Service has made no aerial applications of DDT since 1967. Its use of BHC decreased from 3,980 kg (8,790 lb) in 1966 to 26 kg (57 lb) in 1970. The total use of pesticides in these programs has been reduced from about 613,000 kg (1,353,000 lb) in 1965 to about 140,000 kg (310,000 lb) in 1970.

(ii) Herbicide use: Herbicides are used in silviculture more frequently than insecticides and fungicides, but still only a very small portion of forestland is treated with herbicides in any given year.[90]

Herbicides are used mostly to control undesirable plant species and weeds in new plantings. Herbicides have also helped to prevent forest fires by reducing growth of combustible plant materials on fire breaks and along forest roads.

The U.S. Forest Service sprayed 108,300 hectares (268,666 acres) for the control of noxious weeds or undesirable woody vegetation in 1969. This included about 33,600 hectares (83,000 acres) treated with 2,4,5-T, alone or in a mixture with 2,4-D.[45]

The USDA[88] estimated that 187,000 hectares (463,000 acres) of forest plantings (presumably including publicly as well as privately owned lands) were treated with chemical herbicides in 1968, an increase from an estimated 111,000 hectares (274,000 acres) treated in 1962.

(iii) Fungicide use: Forest diseases reduce the utility of trees for recreation, game management, and for timber production. They kill trees, discolor foliage, retard growth, cause decay leading to breakage and windfall, and destroy wood in use. The U.S. Department of Agriculture[87] estimates that annual losses of timber production due to forest diseases are at 47 million m^3 (20 billion board feet), enough lumber to build 2 million 5-bedroom frame houses.

Fungicides are used to a small extent for the control of diseases on growing stands of timber. Much larger quantities of fungicides are used for wood preservation; some of these are applied directly in conjunction with logging operations. An estimated 17 million m^3 (600 million ft^3) of wood are treated annually with wood preservatives in the United States.

The major pesticides used to treat lumber and fencing materials for rot prevention are creosote and pentachlorophenol.[92]

The effect of aerially applied forest pesticides on water quality depends on the initial distribution of the chemical among components of the forest environment, and the movement of the chemical among and its persistence within each component of the environment. Norris and Moore[71] have made a review on the subject, which is summarized below:

- Aerially applied pesticides will be distributed initially among four components of the forest environment: air, vegetation, forest floor, and surface waters, as shown in Figure 4-1 presented by Foy and Bingham.[26] The amount of chemical entering each portion of the environment will be determined by properties of the chemical, the equipment used, the application technique, and environmental factors.

- Sometimes a large portion of aerially applied pesticides may not reach the target area. This problem can be minimized by using proper application techniques and spraying when weather conditions are favorable.

- Airborne chemicals can be degraded, taken up by plants, adsorbed on various surfaces, or moved as fine droplets (drift) or vapor (volatiles) to other locations where they may settle to the earth or be washed out with rain.

- The amount of spray material intercepted by vegetation depends on the nature and density of the vegetation and physical characteristics of the spray material. Chemical intercepted by vegetation may be volatilized to the atmosphere, washed off by rain, or adsorbed on the leaf surface and brought to the forest floor by falling leaves. The small amounts of pesticides which are absorbed and translocated to other parts of the plant may be degraded by plant metabolism, excreted into the soil from roots, or stored.

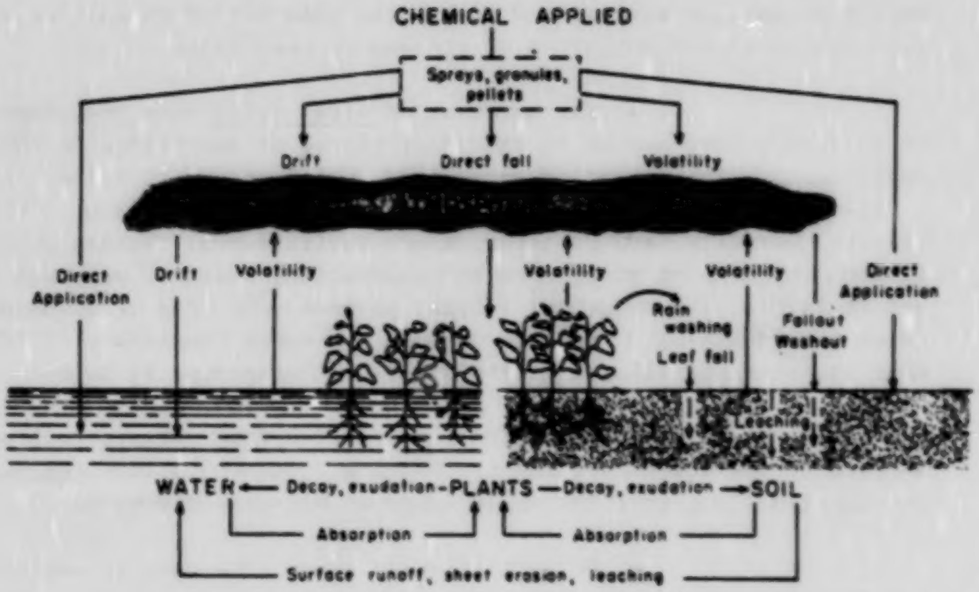
CHEMICAL APPLIED
Sprays, granules, pellets
Drift
Direct fall
Volatility
Direct Application
Drift
Volatility
Volatility
Volatility
Direct Application
Rain washing
Fallout Washout
Leaf fall
Leaching
WATER
Decay, exudation
PLANTS
Decay, exudation
SOIL
Absorption
Absorption
Surface runoff, sheet erosion, leaching

Figure 4-1 - The Distribution and Fate of Chemicals in the Environment (After Foy and Bingham[26])

- The forest floor is a major receptor of aerially applied spray materials. Chemicals in the forest floor may be volatilized and then reenter the atmosphere, be adsorbed on soil colloids and organic matter, leached through the soil profile, adsorbed by plants, or degraded by chemical or biological mechanisms.

- The portion of the spray material which is not lost as drift or intercepted by vegetation on the forest floor will fall directly on surface waters, and offers the greatest potential for short-term but high-level contamination of streams by pesticides.

- The movement of spray drift from treatment areas to surface waters may be an important source of pesticides in the aquatic environment. The amount of spray drift which occurs is influenced by the carrier, the size of the droplets, and the height of release. Wind speed, relative humidity, and temperature are environmental factors which influence the droplet size, rate of evaporation, speed of vertical descent, and therefore, the extent of lateral movement.[38] The relationship between the lateral and vertical movement of spray droplets of different mean diameters is illustrated in Figure 4-2 presented by Reimer, et al.[77]

- Pesticides are carried from spray deposits to streams by surface runoff and/or leaching. In both situations pesticides are carried along in solution or adsorbed on suspended matter.

- Conditions which retard the rate of surface runoff and favor infiltration will minimize the immediate level of stream contamination. This will also reduce the long-term stream load of pesticide because a long residence time in the soil provides greater opportunity for degradation and adsorption.

- The amount of chemical actually entering a stream due to surface flow will be influenced by: distance from stream course to closest point of chemical application; infiltration properties of soil or surface organic matter; rate of surface flow; and adsorptive characteristics of surface materials.

- Leaching or subsurface flow of pesticides is a relatively slow process capable of moving only small amounts of chemicals short distances. Harris[36,37] has determined the relative mobility of

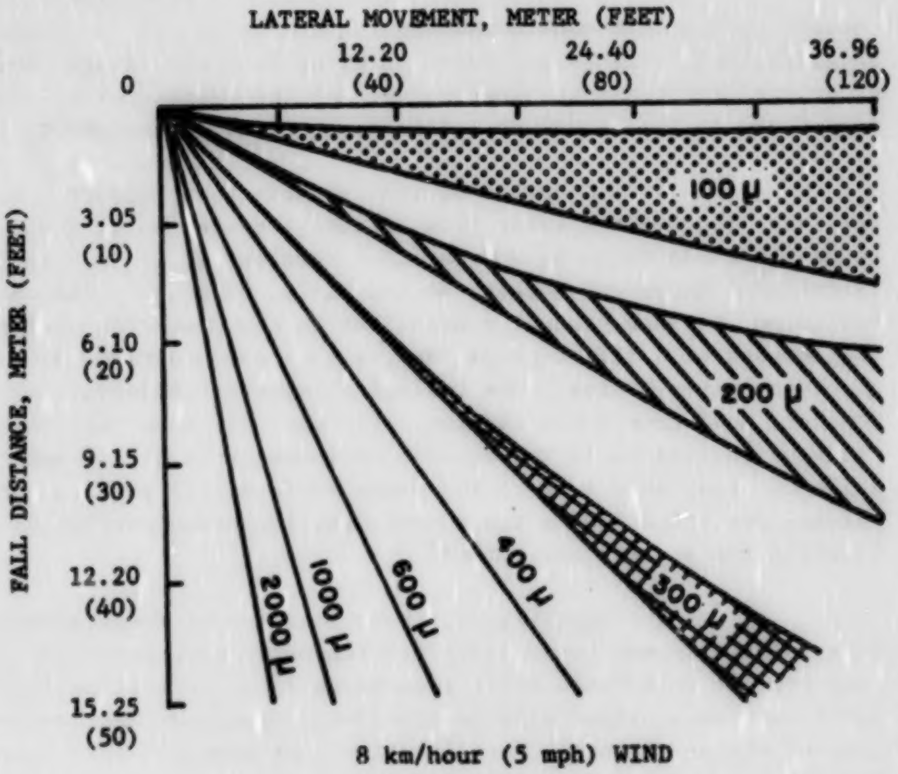

Figure 4-2 - Lateral Movement of Spray Particles of Various Diameters Falling at Terminal Velocity in a 8 km/hour (5 mph) Crosswind. Shaded areas indicate uncertainty due to varying droplet evaporation (from Reimer, Byrd, and Davidson[77]/

pesticides in soil columns leached with water (Figure 4-3). Herbicides in general are more mobile in soil than insecticides.

- Only small quantities of pesticide will enter the aquatic environment due to the washing action of rain on vegetation overhanging stream courses and leaves falling into the water. Some pesticides are excreted from plant roots, but the quantities are small and only roots in the stream or hydrosoil would add chemicals to the water.

A number of studies have been conducted for observing pesticide residues in water from treated forested watersheds. The studies include those by Norris[67-70/] Marston, et al.,[58/] Tarrant, et al.,[84/] Lawrence,[49/] Reese and Becker,[76/] and Davis, et al.[18/] The data are insufficient to draw general conclusions on how pesticide application to the forests will affect pesticide residues and aquatic life in the receiving water bodies. The following important observations were, however, made from these studies: (1) the most important mechanism of entry of pesticides to the aquatic environment is direct application or drift of spray materials to the water surface; (2) surface runoff during intense precipitation is the second most important carrier of pesticides entering the aquatic environment.

(b) Fertilizers: Fertilization of forested watersheds is a relatively new but rapidly growing management practice. Selected tree species on certain soils respond well to the application of chemical plant nutrients, especially to nitrogen. Groman[34/] has reviewed the current status of forest fertilization. At present, fertilizer use on forests is centered in the Pacific Northwest Douglas fir region and in the southern pine region. In addition, the young stands of commercial redwood in northern California and the western hemlock-sitka spruce along the coasts of Alaska, Washington, and Oregon are judged to have a potential for responding economically to applications of fertilizer.

In the Pacific Northwest, forest fertilization with nitrogen started in 1965, reached a level of 47,600 hectares (118,750 acres) in 1970, and is anticipated to be 101,000 hectares (250,000 acres) per year from 1975-1980.

Forest fertilization in the South started in 1963 on a limited basis; in 1971 an estimated 44,400 hectares (110,000 acres) were fertilized.

Urea has been the most frequently used forest fertilizer and is preferred to other fertilizer forms because of its high nitrogen

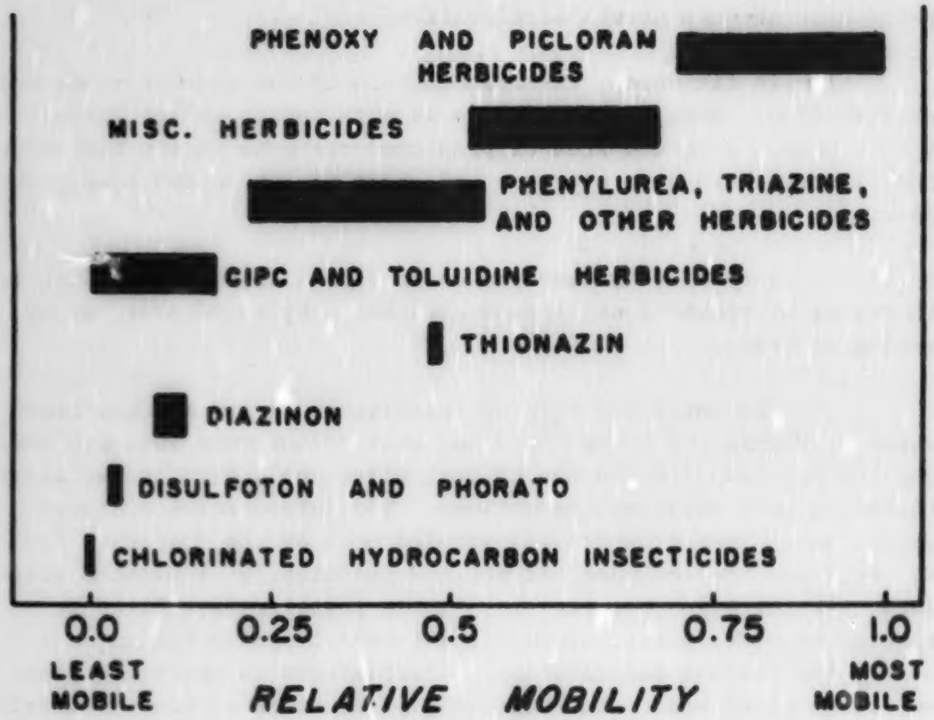

Figure 4-3 - Relative Mobilities of Pesticides in Subirrigated Columns of Soil (From Harris[36,37])

content (46% by weight) and its pelletized form which reduces fertilizer loss by drift. Nitrogen application rates range up to 224 kg/hectare (200 lb/acre).

Response of Douglas fir to nitrogen fertilization has averaged about 30% during a 5 to 7 year period, and trees as old as 300 years have shown a growth acceleration.

In the South, the Southeastern upland pine responds well to fertilization. Here nitrogen alone is expected to enhance growth by about 5% a year. A second area of predicted response is the flatwoods coastal plains, where both nitrogen and phosphorus give increase growth of pines.

Both nitrogen and phosphorus fertilizers are applied to forest stands by conventional ground equipment, by helicopter, or by fixed-wing aircraft.

The entry and fate of fertilizers in streams has been discussed by Norris and Moore.[71] They stated that many concepts concerning the initial distribution of pesticides apply also to fertilizers, but there are some important exceptions. The introduction of large, specially coated urea granules has enabled most of the dispensed fertilizer to reach the intended target, and practically eliminated drift problems. Furthermore, because very little granular fertilizer is intercepted by a dry forest canopy, the forest floor is the major receptor. The initial distribution of fertilizers is therefore restricted to the forest floor and to the exposed surface water within the treated areas.

With an appreciable amount of precipitation, urea may readily move into the forest floor and soil because it is highly water soluble. Under normal conditions, urea is rapidly hydrolyzed to the ammonium ion by the enzyme urease. Nitrogen in this form is rapidly fixed to the soil particles (ion exchange mechanism) where it is relatively available to the tree roots. When moisture is limited, however, urea granules may be slowly hydrolyzed on the forest floor, resulting in a loss of ammonia nitrogen by volatilization.

Fertilizer nitrogen may enter streams by one of several routes. The greatest potential source is direct application to exposed surface water. Overland flow, or surface runoff, when it occurs, is an important carrier of fertilizer nitrogen to the surface waters. Subsurface drainage is also a possible route of entry of soluble forms of nitrogen into streams.

Limited studies have been conducted to date to sample and analyze stream flow from fertilized watersheds or portions of drainage areas. Reports of such studies include those by Aubertin,[4] Burroughs and Froehlich,[15] Klock,[46] Malueg, et al.,[57] McCall,[59] Moore,[62] Thut,[86] Terry and Thut.[85] In all investigations, application was made by helicopter. Nitrogen fertilizers, particularly urea, were tested in all studies except for the study by Terry and Thut[85] in which phosphate fertilizer was applied. Groman[34] made the following summary of major findings on the effect of nitrogen fertilizer on water quality.

- Urea-N and Kjeldahl-N reached short-lived peak concentrations shortly after fertilizer application, and returned to pretreatment levels within several weeks. Strong evidence is presented that the initial increase of urea-N concentrations was primarily due to direct application to surface waters; this contention is substantiated by low initial concentrations where surface waters were intentionally avoided during application.

- A small increase in ammonia-N above pretreatment levels was observed shortly after application. Concentrations quickly returned to pretreatment levels; the magnitude and duration of ammonia-N loss appeared to be associated with surface water application and with volatilization and nitrification losses dependent upon climatic conditions immediately after application.

- Loss in the form of nitrite-N was minimal and insignificant, apparently due to rapid conversion of nitrite-N to nitrate-N through nitrification.

- Nitrate-N contributed to the greatest and most persistent loss of nitrogen on all study areas. The initial significant loss occurred within a period of several days after application, subsequent substantial losses were associated with precipitation. Virtually all of the nitrogen losses after the initial peaks associated with application were in the form of nitrate-N.

- Short-lived and inconsequential ammonium-N losses immediately preceded the nitrate-N losses, and coincided with the initial onset of precipitation.

- Data from one study suggest the possibility of significant interactions involving urea fertilization and discharge of cations from the watershed. A definite increase in the concentrations of calcium, magnesium, sodium, and potassium in the stream following fertilization was observed.

- Losses of applied nitrogen to stream channels ranged from inconsequential to a maximum of 3%. Data vary according to stream surface area, rate and consistency of application, and other factors unique to each study, but approximately one-third to one-half of the total nitrogen loss may be associated with direct application to the surface water and immediate riparian zone.

The effect of aerial phosphate fertilization on water quality has been studied by Terry and Thut[85]. A 4-year old loblolly pine plantation was fertilized by helicopter with 336 kg/hectare (300 lb/acre) of 45% triple superphosphate. The site was a wet mineral soil low in phosphorus, the trees were planted on raised beds, and the entire area was drained by open ditches. Fertilizer was never applied closer to any drainage ditch than 7 m (25 ft).

The phosphate phosphorus (PO_4-P) was monitored in drainage waters. The background level of PO_4-P before fertilization was 13 ppb. A 0.51 cm (0.2 in.) rain caused the level to reach 19 ppb, and a 3.56 cm (1.4 in.) rain was responsible for a level of 176 ppb on the third day after fertilization. On the seventh day, and thereafter, the levels ranged between 9 and 24 ppb, with a median of 16 and a mena of 17 ppb.

(c) Fire retardants: Fire retardants used in silviculture include water, water plus a wetting agent, borates, bentonite clays, and currently Firetrol® (ammonium sulfate) and Phoschek® (diammonium phosphate). Borates and bentonites are no longer used extensively. Dodge[21] has characterized the two most common fire retardants, Firetrol® and Phoschek® as follows:

- Firetrol® contains ammonium sulfate (fire retardant),as a attapulgite clay (magnesium silicate) as a thickening agent, sodium dichromate as an inhibitor of corrosion, and ferric oxide as a coloring agent so it can be readily seen.

- Phoschek® consists of diammonium phosphate as a fire retardant, sodium carboxymethylcellulose as a thickening agent, "Dowicide A" (sodium orthophenylphenate) as a bactericide, and sodium fluorosilicate as a corrosion inhibitor.

Normal use of fire retardants consists of dropping them from an aircraft ahead of the fire, in an inverted V pattern, at or beyond the crest of a ridge.

The literature does not contain documentation of adverse effects of fire retardants on surface water quality. However, it is apparent that entry mechanisms of fire retardants to streams would be similar to those of fertilizers. The use of fire retardants has the potential of increasing ammonia and nitrate concentrations in streams and lakes. However, the hazard to the water environment is minimized if accidental or improper applications of chemicals to streams or lakes are avoided.

4.3.6 Nutrient cycling: There is much current interest in the loss of nutrient chemicals from forests and the effect of these chemicals on surface water quality. As has been previously discussed, an increase in the nutrient level of a stream may result from the use of fertilizers and fire retardants in forests. Research studies indicate that logging and forest fires may increase nutrient inputs to streams. An understanding of nutrient cycling processes on forestland is needed to explain how this happens.

The nutrient budget in forest ecosystems, similar to an energy budget or a water budget, consists of input, output, and intrasystem movement of nutrients. Brown[9] and Fredriksen[28] recently summarized information concerning nutrient cycles in forest ecosystems, and the effect of forest disturbances on nutrient release.

(a) Nutrient inputs: Sources of nutrient input to the forest ecosystem include soil, rock, and atmosphere. Release of minerals from soil and rock is due to biogeochemical weathering, which is a slow, but continuous process. Weathering rates vary widely among different climatic, topographic, and geologic situations. At higher elevations or northern latitudes, where the climate is cold and dry, biogeochemical weathering rates are extremely slow, as exemplified by shallow and poorly developed soils. The wetter, milder climate usually results in noticeably higher rates of weathering.

From the atmosphere, the nutrients reach the forest ecosystem through one or two pathways, precipitation or fixation. Precipitation is an important source of nutrients for forest ecosystems. Nutrient concentrations in precipitation are relatively constant at any one site, but may vary widely geographically. Levels of air pollution may greatly affect nutrient concentrations in precipitation.

In some ecosystems, nutrients, particularly nitrogen, are fixed directly from the atmosphere by soil organisms. Newton, et al.,[65/] has estimated that nitrifying bacteria may accumulate up to about 290 kg of elemental nitrogen per hectare per year in alder stands in western Oregon.

(b) Intrasystem cycling: A portion of the nutrient input into the forest system is retained or stored. Some nutrients are taken up from the soil by vegetation and may be temporarily stored in the standing biomass. As a forest grows and matures, an increasing proportion of the nutrient capital is tied up in nondeciduous biomass. The nutrients in the nondeciduous parts remain fixed until the plant dies or plant parts fall to the forest floor. Decomposition of this material releases the nutrients, some of which return to the forest soil. Some are taken up anew by vegetation.

(c) Nutrient output: Nutrient losses from the forest system may occur: (1) as dissolved and suspended constituents in streams; (2) by removal of material from the land; and (3) by volatilization to the atmosphere. From the undisturbed forests, nutrient losses are usually very low, in the absence of natural catastrophes. Nutrient export during natural catastrophic flood and erosion events has not been documented. On a longer, geologic time scale, such events may assume greater importance to a forest ecosystem.

Combination of nutrient inputs, intrasystem cycling, and nutrient outputs provides a generalized diagrammatic model for nutrient flow in a forest ecosystem as illustrated in Figure 4-4.

(d) Effect of forest disturbances on nutrient release: From undisturbed forests, stream water contains nutrient constituents not taken up by vegetation or stored in other parts of the forest ecosystem. Nutrients may be released by weathering, lost by leakage from intrasystem cycling, or carried to surface waters by precipitation. In this case nutrient levels are usually low.

When the forest system is disturbed, such as by logging and burning, the intrasystem cycling of nutrients will be disrupted. Trees no longer take up nutrients, and the nonmerchantable parts of trees increase forest litter. Increased temperature and water content of the soil accelerate the activity of microorganisms that break down forest litter. The increased activity of the microorganism system raises the bicarbonate anion level and leaches cations from the system.

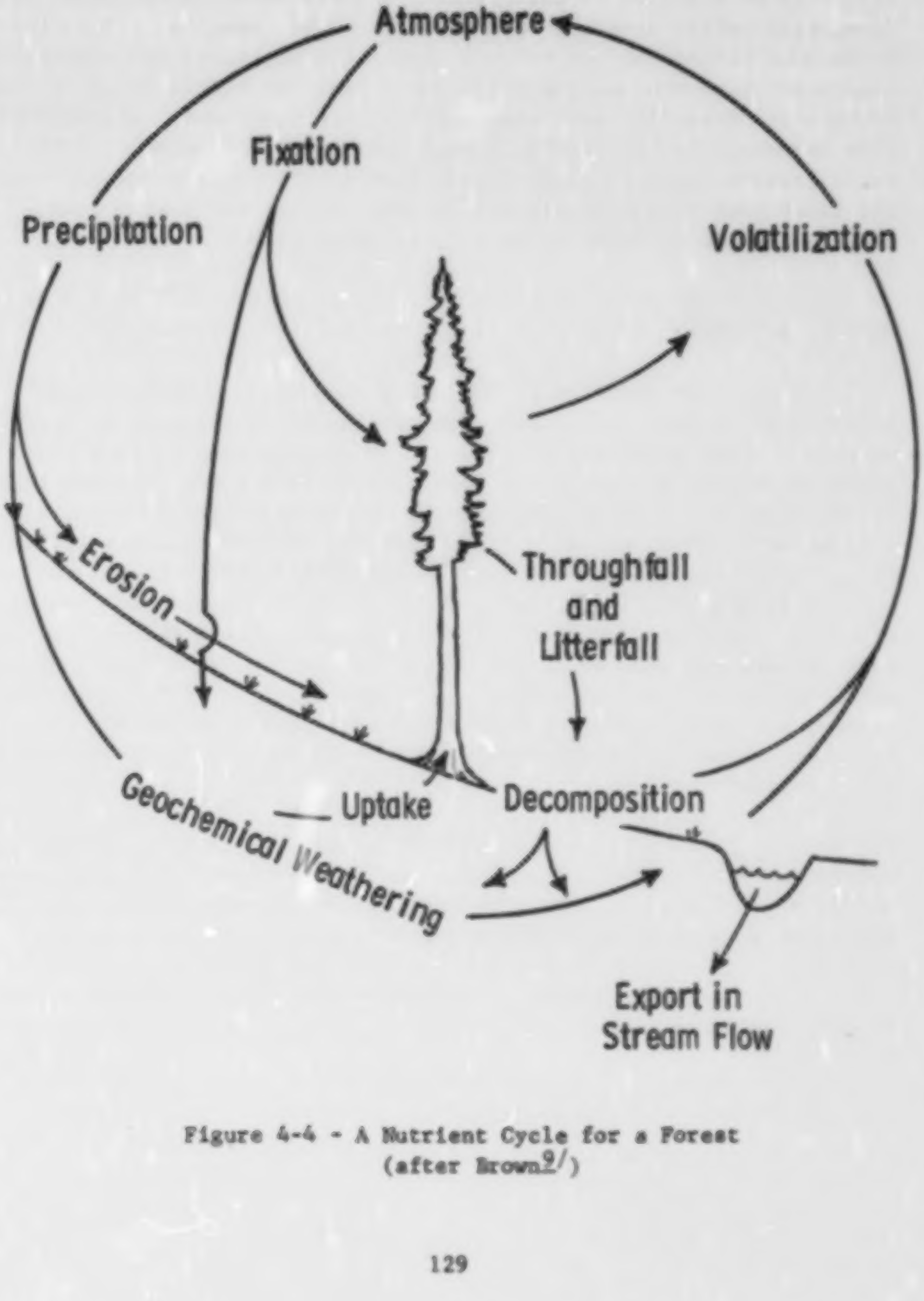
Atmosphere
Fixation
Precipitation
Volatilization
Erosion
Throughfall
and
Litterfall
Uptake
Decomposition
Geochemical Weathering
Export in
Stream Flow

Figure 4-4 - A Nutrient Cycle for a Forest
(after Brown[9])

Vegetation destruction in forested watershed has often been shown to result in increases of various nutrient concentrations in surface waters. Likens, et al.,[53] reported a study conducted at the Hubbard Brook Experimental Forest in New Hampshire, on the effect of large scale forest cutting on nutrient release. This watershed was mixed northern hardwood forest on podzolic soils derived from glacial till. After a period of calibration, a small forested watershed was devegetated while a second calibrated watershed remained untreated. Trees were felled but not removed from the devegetated watershed and vegetation regrowth was inhibited for 2 years by herbicide application. Changes in streamflow and water quality were monitored. Annual streamflow increased by 33% the first year and by 28% the second. Nitrate concentrations were 41 times higher than in the undisturbed watershed the first year after cutting and 56 times higher the second year, ranging from 40 mg/liter to as high as 90 mg/liter.

Other cations increased as follows: Ca^{++} by 4.2 times, Mg^{++} by 4.1 times, K^{+} by 15.6 times, and Na^{+} by 18 times.

In addition to the study conducted at Hubbard Brook, three other studies have focused on the impact of forestry on nutrient release. These studies include those at Cascade Range, Oregon;[28] Alsea Watershed, Oregon;[24] and Cedar River watershed[31] in Washington. In the Cedar River study, where nutrient movement through a forest soil influenced by tree removal and the addition of fertilizers was studied, it was concluded that: "the forest soil considered in this study is not subject to leaching losses in spite of its high porosity and low exchange capacity. Only small amounts of nitrogen, phosphorus, potassium and calcium were removed beyond the effective rooting depth during the 10-month period (after treatment) . . . removing the forest vegetation increases the forest floor decomposition as assessed by the elemental release. However, little of this additional release was lost from the soil profile."

From these studies, it is apparent that the degree of nutrient release after disturbances such as cutting or burning varies widely as functions of characteristics of soils, vegetation, and climate, and other factors which describe a watershed.

Commenting on how these factors affect nutrient release, Brown[9] explained that:

> "Soil characteristics, such as porosity and texture, determine the pathway and rate of water movement in or over soil, soil erodibility, and how strongly nutrients will be held within the soil matrix. Vegetation characteristics, such as species composition, influence the rate of nutrient uptake. The revegetation rate influences the rapidity with which recycling begins after system disruption. The form, chemistry, amount, and intensity of precipitation influence the leaching rate."

4.3.7 *Bacteria*:[83] A certain level of bacteria concentration is always present in streams in forested watersheds. Even maximum possible isolation of forested watersheds cannot entirely safeguard the purity of water. Petersen and Boring[73] reported on densities of coliform and *Escherichia coli* serotypes present in two semi-isolated streams in Colorado. Coliform densities were found to be quite uniform over much of the sampling period, but the presence of cattle in the stream and drainage from flood irrigation both steeply increased coliform density.

Tree debris, livestock and wildlife in forested watersheds are sources of organisms in stream water. Pathogens can be attributed to forest workers and recreationists. Discharge of fecal waste, garbage, wastewater, or other polluting materials from conveyances passing through or over watersheds is also a source of bacterial pollution.

There is some evidence that the forest floor can act as a bacterial filter. Nikolaenko[66] found that snowmelt that had passed through a strip of forest on the bank of a reservoir contained fewer bacteria than water that had not passed through the forested strip.

Kunkle and Meiman[48] measured bacterial groups in water from mountain watersheds in Colorado. Total coliform, fecal *Streptococcus*, and fecal coliform bacterial groups were closely related to the physical parameters of the stream and were especially dependent on the "flushing effect" of runoff from snowmelt and rain, summer storms, or irrigation. The seasonal trend for all bacterial groups was similar: (1) low counts prevailed while the water was at 0°C, although bacteria from all groups were identified during winter; (2) high counts appeared during rising and peak flows caused by June snowmelt and rain; (3) a short "postflush" decrease in bacterial counts took place as the runoff receded in early July; (4) higher bacterial counts were again found in the July-August period of warmer temperatures and low flows; and (5) counts declined in September.

The causes of variation in bacterial numbers in a small, unpolluted stream were studied by Morrison and Fair.[63] These authors concluded that the most important cause was summer rainstorms of short duration, which cause overland flow. When streamflow is stable during periods of no precipitation, bacterial numbers can be related to the size of the water-streambed contact surface. As streamflow increases after precipitation, bacteria can be deposited in the groundwater associated with the stream, and later released into the stream as it recedes. Bacterial numbers fluctuate during the winter even when temperatures are as low as 0°C to 5.5°C. When cattle and wildlife are concentrated in areas adjacent to the stream, the bacterial density of the stream also rises.

4.4 Prediction of Pollution from Silvicultural Activities

4.4.1 Overview: The present state-of-the-art on prediction of pollution from forestlands is very crude. There are no universally applicable methods which can be used to predict the quality and quantity of pollution from a forested watershed. However, this study identifies some methods which have been used on certain forest areas. These methods will be presented in the following paragraphs. Depending on the local situations, the water quality planner/engineer may directly use them as predictive tools, or he may use them as references for developing necessary tools for quantifying nonpoint source pollution in his area.

One type of method is concerned with prediction of soil erosion and sediment production. This type of method is discussed at length in Section 4.4.2. Rates of soil erosion directly affect suspended sediment levels in surface waters. A methodology which is called FASS (First Approximation of Suspended Sediment) has been proposed to approximate suspended sediment levels based on erosion prediction methods and hydrologic characteristics of watersheds. FASS is presented in Section 4.4.3. Section 4.4.4 presents a method which deals with prediction of thermal effect resulting from devegetation of forested watersheds. Prediction methods are not available for other pollutants, such as pesticides, fertilizers, fire retardants, organic waste, nutrients, and bacteria.

4.4.2 Prediction of Soil Erosion and Sediment Production: Sediment from forest areas may be attributed to four different production processes: surface erosion, gully erosion, mass soil movement, and channel erosion. Prediction methods pertinent to these processes are discussed below.

(a) Surface erosion: The following components significantly affect the water erosion of soil surfaces: (1) soil characteristics; (2) topographic characteristics; (3) land cover conditions; (4) regional rainfall characteristics; and (5) erosion control practices. The relative susceptibility of the soil to the erosion process is termed erodibility. In general, the finer textured soils--high in silts and clays--are more erodible than the coarser textured sandy soils. The topographic characteristics which affect soil erosion are the slope of the soil and the length of slope. Generally, soils with steeper and longer slopes are more susceptible to erosion than lesser and shorter slopes. The land cover factor refers to the ability of a cover, such as crops, grass, and trees, to absorb the impact energy of rainfall. The rainfall characteristics consider the amount of rainfall and kinetic energy of raindrops, which directly effect the detachment of soil and initiate erosion. Erosion control practices are those which reduce the erosion potential of the runoff by their influence on drainage patterns, runoff concentration, and runoff velocity.

The essential factors discussed above have been considered entirely or partially in the Universal Soil Loss Equation, and the Musgrave Equation, proposed by Wischmeier and Smith,[98/] and Musgrave,[64/], respectively. These equations were originally developed to predict erosion from croplands, but later were adapted to certain forestry areas. The reader is referred to Section 3.0, of this report and references 1, 64, 95-98, for the use and limitation of the Universal Equation and the Musgrave Equation. While methods used for the evaluation of soil, topographic, and rainfall characteristic factors included in the soil loss equations are commonly used in soil loss predictions, and have been discussed in Section 3.0 of this report, evaluation of Cover and Control Practice Factors pertinent to forestry situations deserves special mention.

The Cover Factor used in the soil loss equations refers to the ability of a cover, such as vegetation, to reduce erosion loss. In forests, a layer of compacted decaying duff or litter several inches thick is very effective against water erosion. Research results indicate a value of Cover Factor as low as 0.001 for woodland with a 100% cover of such duff.[96/]

For forests, Wischmeier[96/] has developed a procedure for approximating Cover Factor based upon three separate and distinct but interrelated zones of influence: (a) the vegetative cover in direct contact with the soil surface; (b) canopy cover; and (c) effects at and beneath the surface. Typical values for Cover Factor for woodland are included in Table 4-5.

TABLE 4-5

COVER FACTORS FOR WOODLAND[96]

Stand Condition	Tree Canopy[a] % of Area	Forest Litter[b] % of Area	Undergrowth[c]	Cover Factor
Well stocked	100-75	100-90	Managed[d]	0.001
			Unmanaged[d]	0.003-0.011
Medium stocked	75-40	90-75	Managed	0.002-0.004
			Unmanaged	0.01 -0.04
Poorly stocked	40-20	70-40	Managed	0.003-0.009[e]
			Unmanaged	0.02 -0.09

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[a] When tree canopy is less than 20% the area will be considered as grassland or cropland for estimating soil loss.

[b] Forest litter is assumed to be at least 5 cm (2 in.) deep over the percent ground surface area covered.

[c] Undergrowth is defined as shrubs, weeds, grasses, vines, etc., on the surface area not protected by forest litter. Usually found under canopy openings.

[d] Managed--grazing and fires are controlled; unmanaged--stands that are overgrazed or subjected to repeated burning.

[e] For unmanaged woodland with litter cover or less than 75%,Cover Factor values should be derived by taking 0.7 of the appropriate values in Table 1 of Ref. 96. The factor of 0.7 adjusts for the much higher soil organic matter on permanent woodland.

It should be pointed out that tree canopy, forest litter thickness, and undergrowth conditions are only part of the parameters to be recognized. In most cases, grass cover and stone content as well as type of overstory also need to be assessed.

The Erosion Control Practice Factor for croplands denotes some soil conservation method other than vegetation management, such as strip cropping, contouring, or terracing. For forests, control practice can be exemplified by the use of buffer strips, and/or other practices which affect patterns of drainage from roads, skid trails, clearcut areas, etc. Values of control factor associated with various practices in forestry are yet to be defined.

(b) Mass soil movement and channel erosion: In a USDA study on the sediment yield from the Eel and Mad River basins,[93] the sediment contribution from mass soil movement and channel erosion was estimated by using aerial photographs. On recent aerial photographs, the location of landslides or streambank erosion sites were identified. On the photographs measurements were made of the cross-sectional area and depth of voided area of landslides, and channel area and channel depth of channel erosion sites. The measurements were repeated on older aerial photographs covering the same area. The amount of material eroded in the time span is represented by the difference in volume measured on both sets of photographs. Dividing this volume by the number of years between the photo-takings gives the estimated annual volume of sediment produced by landslide or streambank erosion.

(c) Gully erosion: Sediment production from gullies can be estimated by using the same methodology as that for landslide and channel erosion. Dissmeyer[20] suggested Equation (4-1) for such estimation:

$$G = F\left(\frac{L_g X}{Y}\right), \qquad (4\text{-}1)$$

where G = gully erosion,

F = conversion factor,

L_g = gully length,

X = average gully cross-section eroded in years of estimate, and

Y = years of estimate.

4.4.3 Prediction of suspended sediment concentrations: Water quality planners are more concerned with the quantitative effect of various silvicultural activities on suspended sediment concentrations in surface water than the rate of soil erosion or sediment production. Concerning suspended sediments in water from forestlands, water quality planners may ask, for example, What is the suspended sediment contribution of each land use or disturbance within the forest? What silvicultural activities or land uses are yielding excessive sediment, and why? What control or preventive measures are required to reduce the suspended sediment to acceptable levels? How can the effect on suspended sediment due to various remedial measures be predicted?

(a) Prediction procedures: In this section, a procedure which has been proposed to predict the suspended sediment is presented. It is called First Approximation of Suspended Sediment (FASS), proposed by Dissmeyer.[19,20] Basically, the procedure distributes sediment yield among land uses and/or disturbances above the point of measurement.

The FASS procedure includes the following major steps:

(1) Stratifying the study area using soils, slope, vegetation, land uses, land disturbances, and quality and type of management;

(2) Field sampling strata for erosion and sediment production;

(3) Computing erosion and estimated sediment production volumes for each land use or disturbance;

(4) Computing gross erosion and estimated sediment production of the watershed;

(5) Computing storm flow, base flow, and annual flow for watershed; and

(6) Computing average suspended sediment concentrations for storm flow, base flow, and annual flow.

Estimating erosion and sediment production rate for each land use or disturbance (Steps 1-3): The watershed is stratified based on factors which greatly affect soil erosion and sediment yield. These factors include soil type, ground slope, slope length, soil cover, land use, disturbance, and quality and type of management. Data for each stratum are obtained through literature and field surveys.

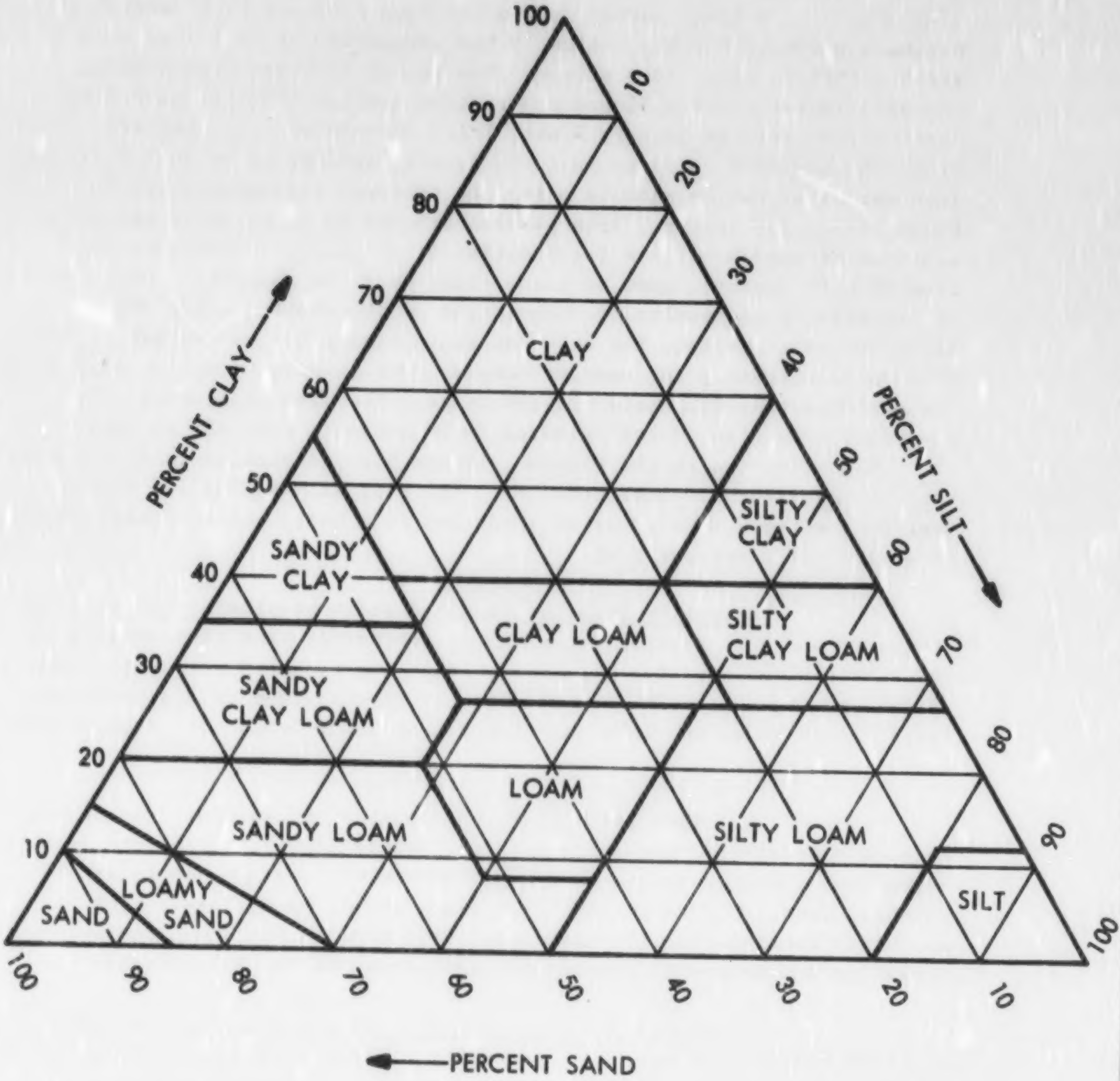
A field survey method has been proposed by Dissmeyer to estimate production ratio, which is the percentage of soil loss from a stratum that is moved to a stream. The method is based upon tracing the soil movement downhill and subtracting erosion that is trapped by obstructions such as litter, limbs, logs, depressions, and benches. Since the sediment delivery ratio is greatly influenced by soil texture, such estimates can be made by using the textural triangle, shown in Figure 4-5. The textural triangle can be used to approximate the percentages of sand and fines (combination of clays and silts) from the type of soil texture, such as loam, silty loam, or whatever. From this information, plus results of observation on the erosion sites and along transport routes, the observer can estimate the percentage of soil erosion that reaches the nearest stream. For example, a medium clay loam has approximately 35% sands and 65% fines. The site inspection of a plot with this kind of soil results in an estimate that 20% of sands and 70% of fines reach the stream. If the plot is eroding at 22.4 metric tons/hectare/year (10 tons/acre/year) the plot is yielding 1.6 metric tons/hectare (0.7 tons/acre) of sands and 10.2 metric tons/hectare (4.55 tons/acre) of fines per year.

Computing gross erosion and sediment production (Step 4): The amount of soil erosion and sediment production from each stratum is calculated by multiplying the erosion rate and sediment production rate by the stratum area. The sum of these by disturbances (roads, yarding areas, etc.) gives the total erosion and sediment production from forestland.

In river basin planning, sediment production from channel erosion, landslides, and gully erosion, should also be taken into account. Furthermore, contributions from the nonforested areas, such as agricultural lands, highways, and urban areas should be included. The amount of erosion from all these processes from forested and nonforested areas are summarized to produce the gross erosion of the watershed.

Computing storm flow, base flow and annual flows (Step 5): Research has demonstrated that generally a large portion of sediments is carried by direct runoff during storms, or the so-called storm flow. The remaining portion is carried by base flow. Dissmeyer has suggested that average suspended sediment concentrations be estimated for a year, and for both storm flow periods and base flow periods.

For a watershed, storm flow volumes are computed using USGS Water Supply Papers and the following equation:[54]


100
90
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10
PERCENT CLAY
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90
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PERCENT SILT
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50
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30
20
10
PERCENT SAND
CLAY
SILTY CLAY
SANDY CLAY
CLAY LOAM
SILTY CLAY LOAM
SANDY CLAY LOAM
LOAM
SANDY LOAM
SILTY LOAM
LOAMY SAND
SAND
SILT

Figure 4-5 - Textural Triangle of Soils (after Dissmeyer[20]

$$N = \left(\frac{A}{2.58}\right)^{0.2} , \quad (4\text{-}2)$$

where N = time for terminating direct runoff, days, and
A = drainage area, km^2.

This equation was established based on the observation that, for a given watershed, the time of direct runoff is relatively constant from storm to storm.

The storm flow volume is the total volume from the time of the first significant rise to N days after the peak. The annual storm flow volume is the sum of storm flows in a year. Base flow is the difference between total annual runoff and storm runoff.

Computing average suspended sediment concentrations for storm flow, base flow and annual flow (Step 6): If a stream has a water quality monitoring station which measures suspended sediment, and the average annual suspended sediment concentration is available, the average sediment concentrations during storm flow periods can be approximated by

$$WQ_s = \frac{P_s WQ_m}{Q_s} , \quad (4\text{-}3)$$

where WQ_s = average suspended sediment concentration (mg/liter or ppm) in storm flow,

P_s = proportion of sediment carried during storm flow period,

WQ_m = average annual suspended sediment concentration (mg/liter or ppm), and

Q_s = proportion of annual runoff contributed by storm flow.

The proportion of sediment carried during storm flow periods varies, but research results generally indicate a range of 0.80 to 1.00. A good approximation would be 0.90[32,44] if no better data are available.

The remaining sediment would be yielded during the base flow periods. Therefore, the average suspended sediment concentration during base flow can be approximated by

$$WQ_b = \frac{(1-P_s)WQ_m}{(1-Q_s)} \quad , \tag{4-4}$$

where WQ_b = average suspended sediment concentration (mg/liter or ppm) in base flow.

When measured suspended sediment data are not available, Eq. 4-5 can be used to approximate average sediment concentration for annual flow:

$$WQ_m = \frac{P_b W_s}{Q_a} \quad , \tag{4-5}$$

where W_s = annual gross sediment yield,

Q_a = annual flow volume, and

P_b = proportion of sediment production which reaches the point of measurement.

The factor P_b is included in Eq. 4-5 to take into account the effect of sediment sinks during stream transport. Values of this factor should be evaluated based on stream conditions and characteristics of soil sediment, etc. (Note: Eq. 4-5 is added, in this presentation of FASS, by the authors of this report.)

FASS can also be used to identify problem areas, to prescribe control measures to reduce suspended sediments, and to evaluate the effectiveness of remedial actions. To accomplish this, the procedure described above is expanded to include the following steps.

Step 7 - Distributing sediment yield among land uses and disturbances in proportion to their individual contribution to the gross sediment production.

Step 8 - Identifying land uses and disturbances that need suspended sediment contribution reduced, and prescribing corrective measures.

Step 9 - Projecting benefits of recommended sediment control programs.

Distributing sediment yield among land uses and disturbances (Step 7): The sediment concentrations for either annual, base, or storm flow periods are distributed among land uses and disturbances in proportion to their individual contribution to the gross sediment production. For example, if skid trails produce 7% of the estimated sediment production and the average storm flow concentration is 70 ppm, then the contribution by skid trails is 4.9 ppm.

Identify land uses and disturbances that need suspended sediment contributions reduced and prescribe corrective measures (Step 8): The previous step identifies the relative contribution of each land use or disturbance to the total suspended sediment concentration. For example:

Skid trails	4.9 ppm
Spur roads	1.3
Mechanical site preparation	56.1
Logging	0.4
Fire	6.9
Log decks	0.4
Total	70.0 ppm

In this example, mechanical site preparation would gain our first attention, followed by fire, skid trails, and spur roads.

Corrective measures would be prescribed and evaluated by the Universal or Musgrave Equations and the FASS Procedure. From these evaluations, the benefits of the recommended sediment control program would be evaluated and the expected future water quality could be predicted (Step 9).

FASS using reservoir sedimentation data: When suspended sediment data are not available, but reservoir sedimentation is available, FASS contains a procedure for approximating suspended sediment concentrations using soils information and reservoir sediment data. This procedure has been discussed in detail by Dissmeyer.20/

(b) Methods of data collection: The required data for prediction of soil erosion and sediment production, and approximation of suspended sediment concentration from a given watershed, are obtained from a survey of relevant literature (presurvey review), and from on-site inspection (field survey).

In the following paragraphs, general approaches to conducting presurvey reviews and field surveys are presented. This material is synopsized from the U.S. Forest Service Manual, "Hydrologic Surveys and Analysis," (FSM 3570).

Presurvey review: At the outset of the survey, considerable basic data are usually available in the form of maps, aerial photographs, geology and soil reports, forest survey and range allotment analysis reports, stream flow and precipitation records, research publications, barometer watershed results, etc. These data should be collected and reviewed prior to a field investigation to gain a general understanding of the landscape, the resources, and problems connected with the use of the resources.

A list of data and information sources follows:

1. Topographic maps
   a. Quadrangle maps: Department of the Interior, Geological Survey, Topographic Division; and Department of the Army, Army Map Service
   b. National parks and monuments: Department of the Interior, National Park Service
   c. National forests: Forest Service
   d. Local areas: commercial aerial mapping firms
2. Planimetric maps
   a. Plots of public land surveys: Department of the Interior, Bureau of Land Management
   b. Forest Service planimetrics
   c. County maps: county surveyor or county engineer
   d. Federal Reclamation Project maps: Department of the Interior, Bureau of Reclamation
3. Aerial photographs
   a. The following federal agencies have aerial photographs of parts of the United States: Department of the Interior,

Geological Survey, Topographic Division; Department of Agriculture--Agricultural Stabilization and Conservation Service, Soil Conservation Service, and Forest Service; Department of Commerce, National Ocean Survey; Department of the Air Force; and National Aeronautics and Space Administration. Also, various state agencies and commercial aerial survey and mapping firms have inventories of aerial photographs.

4. Transportation maps

   a. State transportation maps: Department of Transportation, Bureau of Public Roads

   b. State and county highway maps: state highway departments

   c. Sectional aeronautical charts: Department of Commerce, National Ocean Survey

5. Geology

   a. Geologic maps and reports: Department of the Interior, Geological Survey, Geologic Division; state geological surveys or departments; and logged wells

6. Soils

   a. County soil survey reports: Soil Conservation Service and Forest Service

   b. Land-use capability surveys: Soil Conservation Service

   c. Land classification reports: Department of the Interior, Bureau of Reclamation

7. Vegetation

   a. Forest survey reports: Forest Service

   b. Range survey reports: Forest Service and Soil Conservation Service

   c. Game census reports: federal and state fish and wildlife services

d. Fire statistics: federal and state foresters' reports

e. Cutting records: federal and state foresters' reports

8. Climatological data

   a. Climatological data (monthly and annual summaries): Department of Commerce, Weather Bureau; and power companies

   b. Hydrologic bulletin and technical papers: Department of Commerce, Weather Bureau

   c. Cooperative study reports: Department of Commerce, Weather Bureau; and Department of the Interior, Bureau of Reclamation

   d. Fire-weather reports: Forest Service and state foresters

9. Stream flow data

   a. Water-supply papers: Department of the Interior, Geological Survey, Water Resources Division

   b. Reports of state engineers and other divisions of state governments

10. Sedimentation

   a. Water-supply papers: Department of the Interior, Geological Survey, Quality of Water Branch

   b. Reports: Department of the Interior, Bureau of Reclamation; Department of Agriculture, Soil Conservation Service and Agricultural Research Service

11. Research results

   Technical journals; technical abstract services

12. Basin and project reports and special reports

   Department of the Army, Corps of Engineers; Department of the Interior, Bureau of Land Management, Bureau of Mines, Fish and Wildlife Service, National Park Service; and Environmental Protection Agency; Department of Agriculture, Forest Service and

Soil Conservation Service; state departments of water resources, public works power authorities, and planning commissions

The great variation in the physical factors that affect runoff, soil movement and sediment delivery calls for a careful determination of what is to be sampled. One of the fundamental principles for increasing precision in sampling is to stratify the population into a minimum number of relatively homogeneous units. To achieve this, complex watersheds or parts thereof may be subdivided into physically homogeneous strata that will give the least variation in runoff and soil loss. The strata would be areas where the important factors that affect runoff and soil loss show strong uniformity. These are factors that index characteristics of soils, geology, physiography, vegetation, and land use.

Field survey: Following stratification of the area on the basis of a review of available data, a reconnaissance is made of the watershed in order to observe how the mapped strata appear on the ground and to correct or supplement them if necessary, and to obtain estimates of amounts of erosion and detailed characteristics of the factors that affect erosion and sediment production.

Sampling must be carried out on representative parts of the stratum. The number of samples required depends on what is decided as necessary to provide an adequate knowledge of the characteristics and potentials of the area. The dimensions of certain strata, and knowledge of soil, cover, and land-use problems as obtained on the reconnaissance investigation, will serve as guides to the location and amount of sampling required.

Strata will be sampled by significant sources of runoff and sediment. In all cases this will involve separate sampling for the vegetated areas and roads and skid trails. Where other significant sediment sources prevail, such as channels, gullies, landslides, and strip-mined areas, separate sampling should be carried out on each source.

Field data to be collected during field surveys for the areas underlined above are briefly discussed below.

1. Vegetated area: Field plot and transect procedures are used to obtain the following information from the vegetated watershed surfaces. The information is used to estimate present rates of soil loss and runoff; and future rates where they will be changed by land use, vegetative treatment, and management practices.

• Geology and soils: Soil origin, and soil characteristics (soil texture, soil depth).

• Sediment delivery ratio: The percentage of soil loss material from a plot that has been moved or could be moved into a stream, depending on topography, vegetative cover, the plot's proximity to a drainage channel, and the presence or absence of impediments to the movement of materials into the stream.

• Physiography: Slope, slope length, slope position, and exposure.

• Vegetative cover: General vegetative type, forest type, stand size, litter depth, humus depth, humus type, crown density, range types, ground cover density, and vegetative disturbance (fire damage, animal damage, logging damage, etc.).

• Land-treatment measures: Vegetative land treatment, and structural or mechanical measures.

• Land status: Land use, ownership, and management status.

2. Roads and skid trails: A sampling of roads and skid trails should be made to determine amounts of soil loss occurring from these uses. Areas bared by roads, trails, and landings should be measured. Depth of erosion on roads is measured along cutbanks as evidenced by gullies and rills on the surface, by the extent the slope toes have moved back from the edge of the road and ditches, and by the length of roots extending from the banks. An estimate is made of the percentage of soil loss that is becoming sediment in streams as was done on the vegetated areas.

3. Channels, gullies, and landslides: Soil loss from active gullies, landslides, and live streams should be estimated if these are significant sources of sediment in the area under investigation. Field sampling includes dimensional measurements of length and cross-sectional areas of gullies, and landslides, etc.

4.4.4 Prediction of thermal effects: A temperature prediction method was developed by Brown[10] using energy budget techniques to predict the magnitude of the change in temperature following forest exposure, such as clearcutting, logging and burning. The model is expressed as

$$\Delta T = \left(\frac{AH}{D}\right)C \quad , \qquad (4\text{-}6)$$

where ΔT = the predicted temperature change in °C (°F),

A = the surface area of the section of the stream exposed (by clearcutting, for example) in m^2 (ft^2),

H = the net heat input to the stream in $Kcal/m^2$-min (Btu/ft^2-min),

D = the stream discharge in m^3/sec (ft^3/sec), and

C, a constant = 1.67×10^{-5} when ΔT is in °C, A in m^2, H in $Kcal/m^2$-min, and D in m^3/sec ($C = 2.67 \times 10^{-4}$ when ΔT in °F, A in ft^2, H in Btu/ft^2-min, and D in ft^3/sec).

Except for H, determination of terms at the righthand side of Equation (4-6) is straightforward. Value of H for the specific area can be measured,[10] or calculated.[11]

Calculation of H can be simplified by considering the solar radiation as the only heat input, and neglecting the effects of convection, conduction, and evaporation. Calculation of the net radiation for specific areas is made by subtracting the amount of radiation reflected from the total amount of incoming radiation. The solar radiation on a clear day can be estimated based on the solar angle, which in general depends upon the season, time of day, and latitude. However, because of the symmetry of the solar path, the hourly value of the solar angle can be predicted based on the sun's angle at solar noon alone. The midday solar angle can be measured with a solar emphemeris.[55]

Methods have been developed for prediction of hourly changes in stream temperature at any time of the day. However, for water quality planning, it is often unnecessary to predict the hourly change if the maximum change is assessed, because the maximum change would be sufficient to permit one to predict any major change in stream ecology.

To predict the maximum change in stream temperature as water flows through the exposed forested area, an estimate of the maximum input of heat must be made. This estimate is made at low-flow periods and by averaging the net radiation about the noon maximum. For the purpose of this estimation, average midday net solar radiation absorbed by streams has been determined based on travel time and solar angle, and is plotted in Figure 4-6.

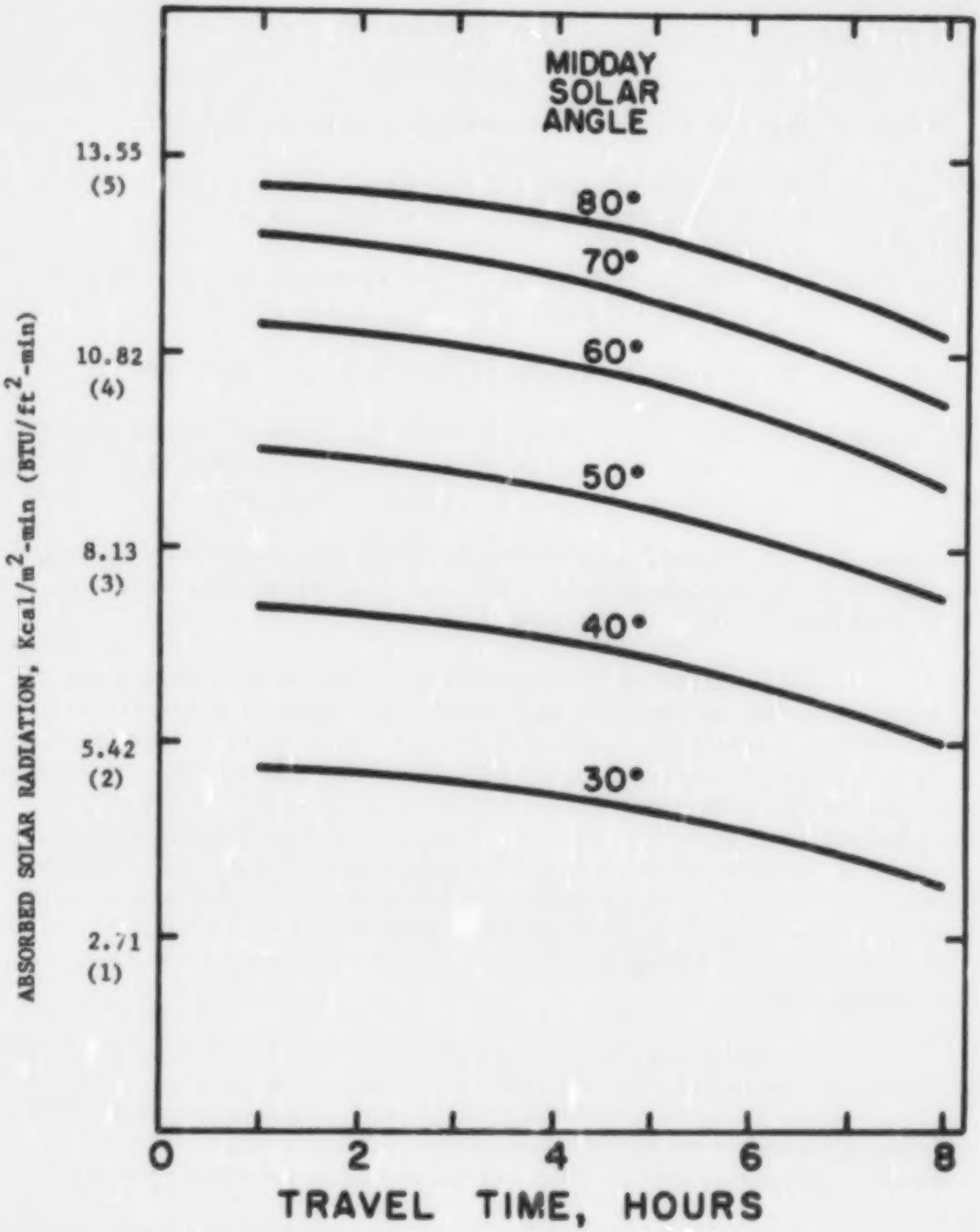

Figure 4-6 - Average Net Solar Radiation Absorbed by Streams Between Latitudes 30N and 50N on Clear Days During Several Periods of Exposure to Different Solar Paths (after Brown[11])

The procedure to estimate the maximum change in stream temperature as a result of exposure to solar radiation, according to Brown,[11] may be summarized as follows:

1. Mark the upstream and downstream boundaries of the exposed forest area.

2. Determine the lowest discharge during the summer and the dates during which it occurs.

3. Determine the surface area of the stream in the exposed area during the low-flow period.

4. With dye, determine the travel time of the stream through the area during the low-flow season.

5. From a solar ephemeris, determine the highest sun angle at solar noon for the period of low flow.

6. Enter Figure 4-6 with the appropriate travel time. Move up to the correct curve for the sun angle at solar noon and read the average radiation in $Kcal/m^2$-min (Btu/ft^2-min).

7. Compute the predicted maximum change in temperature using Eq. 4-6.

According to Brown, et al.,[14] Eq. 4-6 has an accuracy of ± 2°C (± 3°F). This equation has been used successfully on several small streams. There are limitations in applying this equation, however. Limitations chiefly stem from exclusion of heat transfer by evaporation, convection, and conduction when computing H. Brown[8] suggested that this equation should be applied to relatively short stretches of stream, less than 610 m (2,000 ft), and that H in the equation should be reduced by 15% to 20% on streams with solid rock beds, because of conduction.

4.4.5 Predictive methods for other pollutants: After a thorough evaluation of literature and data, this study has concluded that methods are still not available for predicting effects of silvicultural activities on water quality in terms of parameters such as organics, pesticides, nutrients, and bacteria. Most of the pertinent data are results of case studies which depict order of magnitude changes of certain water quality parameters associated with a specific disturbance or treatment in a given locale with its unique natural and operational conditions. It is dangerous to generalize results of such case studies unless research is conducted to further elucidate the processes responsible for the observed changes.

Until accurate prediction methods are available, we recommend that a water quality planner/engineer conduct an input-output analysis to determine what effect the silvicultural activities may have on water pollution in the local area. Sources of some input data, such as type and degree of disturbances, climate, topography, etc., have been given previously. Other information such as application of fertilizers, pesticides, fire retardants, rafting and water storage of logs, etc., may be available from the U.S. Forest Service, Bureau of Land Management, state forestry departments, or private forest industries.

The output data--water quality--may be obtained from existing inventories or by stream monitoring. Methods to obtain this type of data are discussed in the following section.

4.4.6 Monitoring of water quality: There are numerous sources of water quality data which can be used by the planner/engineer to determine the effect of pollution on water quality. Among these are the Environmental Protection Agency, the U.S. Forest Service, the U.S. Geological Survey, the Army Corps of Engineers, and state water pollution control agencies.

Most of these agencies have inventories of data collected by themselves. The EPA's STORET System, however, has data of most of the other agencies. It is a very comprehensive source of water quality data and is highly recommended for planners/engineers. It is in computer-processible form, and data are retrievable at Regional EPA Offices.

When necessary data are not available from existing stations, local water quality monitoring programs must be established to determine the effect of pollution from forestland on water quality. This effect is normally determined by comparing upstream samples to downstream samples. This direct comparison normally will provide useful results in a relatively short period of time. Long term monitoring is essential to provide natural background water quality levels for proper interpretation of upstream and downstream data.

Monitoring should normally be limited to those parameters most likely to be significantly affected by the silvicultural activities. These parameters include water temperature, turbidity, suspended sediment, dissolved oxygen, specific conductance, nutrients, and pesticides. Stream flow should also be measured to assist in interpreting water quality data.

The sampling frequency must be carefully established so that all the ranges of water quality that might be experienced from the silvicultural activity are observed. Monitoring schemes must be process-based. That is, they must be built upon some knowledge of how and when the pollutant is likely to be produced. For example, we know that forest chemicals most frequently enter streams during periods of application. With sediment, we know it enters streams primarily during storm events. For water temperature monitoring, the sampling should be geared to the mid-summer, midday period during hot, clear days.

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5.0 MINING

5.1 Introduction

Mining activities in the United States have affected approximately 5.3 million hectares (13 million acres) of land, according to estimates by the U.S. Department of the Interior. This acreage includes almost 3 million hectares (7 million acres) which have been undercut by mining activities, and more than 1.2 million hectares (3 million acres) disturbed by surface mining activities. The remaining acreage represents land used for containing mining-related mineral waste accumulations. By the year 2000, the Department of the Interior estimates that 12 million hectares (30 million acres) will be affected by mining operations.20/

While the land area presently affected by mining represents only about 0.5% of the United States, the effects of mining upon water quantity and quality are spread over large regions. The effects of mining include pollution of water supplies with mine drainage and sediment.

Pollution from mining operations arises because the hydrology of surface and subsurface waters is altered when the earth's crust is disturbed to gain access to mineral values held within. The quality of these waters very often deteriorates, and the quantity is often redisturbed as a result of mining operations. Water quality deteriorates when water supplies are contaminated with soluble products present in or generated from mining wastes. Water quantity is affected because natural drainage patterns for surface and subsurface waters are altered.8/

5.2 Nature and Extent of Pollution from Mining Activities

5.2.1 General overview: In the ultimate analysis, any disturbance of the earth's crust will alter the environment in the vicinity of the disturbance. The degree to which the environment is altered depends upon the size and depth of the disturbance, the method of the disturbance, and the nature of the disturbed materials. In the case of mining, the purpose of disturbing the earth is to extract mineral deposits. Methods used are determined by the placement of the minerals in the earth. Similarly, size and depth of the mine are determined by the distribution of the mineral at the mining site.

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The extraction of minerals from the earth's crust can be accomplished by a variety of techniques. For minerals deep in the earth, mine shafts are sunk to gain access to the deposit. This method is usually not used if mineral deposits are available for recovery by surface mining techniques. Underground mining techniques do, however, tend to retrieve most of the values in the deposit compared to surface mining techniques.

Surface mining creates more visible defacement of the earth's surface, and results in disturbance of large land curves. Indiscriminate surface mining of the past has created problems which are still present today. However, land disturbed by surface mining can be reclaimed, and techniques are being developed by which mining and reclamation can be integrated almost into a single operation. Modified block cutting in contour surface mining of coal is an example.16/

The most serious pollutant arising from mining activities is the mine drainage generated by oxidation of pyritic materials with air in the presence of water; this drainage is an acidic mixture of iron salts, other salts and sulfuric acid. Mine drainage arises from both underground and surface mining sources, and from coal and many metal mining operations. Coal deposits and so-called hard rock mineral deposits are commonly associated with pyrite and marcasite, which are disulfides of iron. Acid mine drainage can find its way into surface waters, where the acid and sulfate may result in severe deterioration in stream quality. The acid can react with clays to yield aluminum concentrations sufficient for fish kills, and with limestone to yield very hard waters expensive to soften. The acid can also selectively extract heavy metals present in trace quantities in mineral and soil formations, resulting in toxic conditions in lakes and streams.

Mining refuse--waste materials left near the mining site after raw minerals have been cleaned or concentrated--is another source of pollution. Much of this refuse contains pyritic material which can be oxidized to acidic substances. The resultant acid water may remain in the pile until a rainstorm, at which time it is flushed into nearby watercourses. Mine drainage "slugs" during storms are very detrimental to aquatic life in surface waters.

Mining operations also generate wastes, commonly called spoil, in the form of disturbed rock and soil. If this spoil is left in piles, erosion and runoff will carry sediment into streams. This sediment is capable of destroying life in streams, results in decreased capacity of streams and reservoirs, and destroys fish and wildlife habitats.

Improperly impounded sediment may be released suddenly as a mud slide and thus poses a direct threat to life and property.

Mining activities have a pronounced effect on groundwater supplies. The various operations used to mine the mineral deposits can result in alteration of groundwater distribution patterns. Aquifers containing good water can become contaminated because some mining may disturb bedrock formations, which permit mixing of contaminated water with good.

In the western United States, raw metal ores of copper, gold, and silver, etc., are treated so that concentrated ores can be economically shipped to smelters or other metal refiners. The waste residue left behind in the concentration process is retained in ponds. Unless these ponds are carefully sealed, salts will leach into groundwater which can be recovered at a considerable distance from the source. If ponds are located on impervious rock, water trickling through the impounded solids will be discharged as polluted leachate in a spring at the foot of the impoundment.

5.2.2 Acid mine drainage: As stated above, acid mine drainage is the most serious source of pollution from mining activities. It is generally associated with coal mining, although it is not found at all coal mines. It is also a problem in some hard rock mining areas, since hard rock mineral deposits are commonly associated with pyritic-type materials.

Acid mine drainage can arise from both surface mining and from underground mining. It can also arise from undisturbed coal beds.38/ In 1698, Gabriel Thomas observed acid drainage associated with coal deposits in what is now Appalachia: "And I have reason to believe that there are good coals, also, for I observed the runs of water which have the same color as that which proceeds from the coal mines in Wales." Similarly, the presence of acid drainage was an important indicator to 19th century prospectors looking for gold in the western United States.

Any opening in the earth which causes pyritic materials to be exposed to air and moisture is a potential source of mine drainage. Similarly, waste pyritic materials in gob piles, spoil banks, or tailings ponds will react with air and water to produce mine drainage. Moreover, after a particular mining operation is abandoned, mine drainage will continue to be generated unless disturbed land is effectively reclaimed and underground shafts and tunnels are properly shut down.

(a) Formation of acid mine drainage: The chemical reactions producing acid mine drainage are many. The most important, however, are those involving the oxidation of pyrite. Mine drainage from pyrite oxidation is generally shown as occurring in three steps: (1) oxidation of pyrite to ferrous sulfate and sulfuric acid; (2) oxidation of ferrous sulfate to ferric sulfate; and (3) hydrolysis of ferric sulfate.

The oxidation of pyrite to ferrous sulfate and sulfuric acid (step 1) is rapid if the pyrite is exposed to moist air.

Moisture condensation, flooding, and natural drainage processes flush the ferrous sulfate-acid mixtures into watercourses, where dissolved oxygen in the water will slowly oxidize the ferrous iron to ferric iron (step 2). This oxidation may be catalyzed by other metals (i.e., manganese, copper, and aluminum), or by bacteria (*Ferrobacillus ferroxidans*).

Finally, as the ferric sulfate is diluted by a receiving stream, it will be hydrolyzed to form colloidal ferric hydroxide (so-called yellowboy) and sulfuric acid (step 3).

A detailed discussion of the pyrite oxidation sequence outlined above may be found in Attachments C and D to Appendix C of the Appalachian Regional Commission Report entitled Acid Mine Drainage in Appalachia.[38,39]

(b) Neutralization of acid mine drainage: It has long been recognized that the above reactions are insufficient to characterized mine drainage. For example, if the drainage passes through a calcareous shale or limestone region, the acid will be neutralized and converted into calcium (or magnesium) sulfate salinity.

Carbonic acid generated by the neutralization of acid mine drainage will continue to dissolve limestone to produce calcium bicarbonate, the material which provides the natural alkalinity of practically all surface and subsurface waters.

The presence of bicarbonate alkalinity in neutralized mine drainage has important ramifications. Some of this alkalinity can be attributed to ferrous bicarbonate. Ferrous bicarbonate can react with oxygen to form ferric hydroxide and carbon dioxide, thus providing a mechanism for iron oxidation without the formation of sulfuric acid.

If mine drainage passes through noncalcareous clays and shales, it may extract aluminum as aluminum sulfate. Aluminum sulfate can hydrolyze to precipitate aluminum hydroxide and liberate sulfuric acid, through reactions analogous to those with ferric iron.

Many clays contain alkali oxide (potassium or sodium oxide) in significant quantities. A representative chemical analysis of a Pennsylvania clay indicates 6.09% K_2O and 0.17% Na_2O.[35] The presence of alkali oxide in clays provides a neutralization path for acid mine drainage other than reactions with limestone or calcareous shales.

(c) Mine drainage classes: Mine drainage has been categorized into four classes.[4] These classifications are presented in Table 5-1. Distinctions among the various classes are derived from drainage pH (hence acidity), and from the oxidation state of the dissolved iron. The ratio of ferrous to ferric iron is an indicator of the history of the mine drainage. A high ferric iron content may indicate that the drainage has been exposed to air for a relatively long time. The ratio may relate to location or condition of the drainage course, and thus may be potentially useful in prediction tools, this aspect of mine drainage data interpretation has not been explored.

5.2.3 Other types of nonpoint pollutants arising from mining operations: Sediment, leachates of various types (other than mine drainage), radioactivity, and to a limited extent pesticides and fertilizers are generated by mining activities, or as an aftermath to pollution from mining is abetted by subsidence and fracture of geologic formations.

(a) Sediment from mining operations: Surface mining of coal and other sedimentary minerals, e.g., phosphate and iron ore, creates large areas of disturbed land. This disturbed land is highly erodible and can contribute large quantities of sediment to surface waters if the land is not properly reclaimed after mining or if proper techniques for sediment control are not employed in the mining operation.

Processing raw minerals to concentrate ore creates vast piles of finely divided raw materials, called tailings, which are potential sediment problems if not controlled at the processing site. This problem is especially prevalent in the western United States where hard rock minerals have been concentrated, and the resultant tailings are spread over wide expanses of land.

TABLE 5-1

MINE DRAINAGE CLASSES[4/]

	Class I Acid Discharges	Class II Partially Oxidized and/or Neutralized	Class III Oxidized and Neutralized and/or Alkaline	Class IV Neutralized and not Oxidized
pH	2 - 4.5	3.5 - 6.6	6.5 - 8.5	6.5 - 8.5
Acidity, mg/1 $CaCO_3$	1,000 - 15,000	0 - 1,000	0	0
Ferrous Iron, mg/1	500 - 10,000	0 - 500	0	50 - 1,000
Ferric Iron, mg/1	0	0 - 1,000	0	0
Aluminum, mg/1	0 - 2,000	0 - 20	0	0
Sulfate, mg/1	1,000 - 20,000	500 - 10,000	500 - 10,000	500 - 10,000

Thus, sediment is a problem common to most mining operations. The nature and extent of the problem is dependent upon the geographical location of the mining operation, the type of mining employed, the type of mineral being extracted, and the degree of reclamation, including establishment of vegetative cover, used to restore land disturbed by the mining operation.

The following discussion is concerned with sediment from two sources: surface mining of coal, and tailings from hard rock mineral processing.

Sediment from surface mining of coal: Contour mining of coal is the largest single source of sediment from mining operations. Attention has been drawn to this problem because of Congressional inquiry into surface mining.10-13/ Surface mining of coal increased from 7.7 million metric tons (8.5 million tons) in 1920 to 135 million metric tons (149 million tons) in 1947, and to 235 million metric tons (259 million tons) in 1971.42/ The percentage of total coal production using surface methods was 1.5% in 1920, 22.1% in 1947, and 46.9% in 1971.

Sediment problems in mountainous coal-mining areas arise primarily because it is difficult to restore a mountainside excavated to extract its coal values. Traditional contour mining practices have involved the dumping of overburden on the downslope side of the cut in order to expose the coal seam. The material exposed by this indiscriminate dumping is often highly erodible, and can result in excessive siltation of mountain streams and reservoirs.

In addition to downslope dumping of spoil, contour mining also leaves a "highwall," the steep cliff remaining above the cut after coal has been stripped. Highwall materials can erode and deliver sediment to local watercourses, unless runoff is diverted into drainage channels along the top of the cut. If the land is restored to the original contour, no highwall remains.

Siltation from surface coal mining operations in flat country (area coal mining) is less acute than from surface mining in mountainous or hilly regions.

Hard rock mineral processing: The concentration of ore from hard rock mining areas results in large quantities of tailings--waste rock dust removed from the raw ore. Ore-concentrating operations are usually aqueous, and waters containing tailings have in the past been indiscriminately dumped into the nearest stream. This practice has resulted in many miles of sediment-laden stream valleys in the West. In cases where tailings have been impounded, sediment does not constitute a mining pollutant problem.

One case study on the effects of uncontrolled tailings discharges has been conducted along Whitehead Creek in South Dakota.[24] This creek serves as the water supply to the Homestake Gold Mine at Lead, South Dakota. Through the years, Whitehead Creek below the Homestake Mine has become sediment clogged. Sediment from the operation can be traced from the mine to the Missouri River 300 miles away along the courses of the Belle Fourche and Cheyenne rivers, of which Whitehead Creek is a tributary.

(b) Groundwater pollution from mining operations: In many parts of the country, groundwater is a principal source of water for domestic and industrial use. Mining operations often involve processes which disrupt the flow of groundwater.

Blasting operations can fracture local rock strata. These fissures in the bed rock provide entries for mine drainage or saline water to aquifers containing good groundwater.

The sinking of mine shafts or the digging of deep open pit mines can create depressions which are lower than normal groundwater levels. In this event, groundwater will drain into the depressions. In active mining operations, this water must be removed to gain access to the mineral deposit.

In hard rock mining areas, some ores are leached with sulfuric acid to dissolve a metal so that it can be concentrated in a subsequent process. This separation technique, known as leach mining or solution mining, is often employed for the extraction of copper. In the leaching process, the dissolution of copper occurs in ponds which may be located on fractured rock. Leach liquor can seep from these ponds into groundwater, thus polluting it.[48]

When leach mining is employed in areas that receive little rainfall, e.g., Arizona, great care is usually taken to insure that water is conserved. Any losses of leach liquors to groundwater require make-up water, which could be difficult to obtain. In these areas, pollution of groundwater from leach mining operations should be small.

Leachate from tailings ponds located on fractured rock also are potential sources of groundwater pollution. This aspect is discussed in greater detail in the next section

In general, groundwater pollution from mining operations is controllable by sealing or lining the ponds containing polluted water.

(c) Leachate from mining operations: Leachate, the discharge of polluted water arising from water percolation in waste rock piles, is a serious source of pollution. It occurs in coal mining regions where coal refuse, gob piles, and mine spoil are exposed to weathering, and in the West where tailings piles and leach-mining operations are located on fractured rock.

Pyritic wastes in gob piles or in unreclaimed overburden (spoil banks) are serious sources of leachate. The pyrite in these piles will oxidize and form soluble iron salts and sulfuric acid within the pile. Under normal circumstances, these oxidation products remain in the pile until it is flooded with water during a rainstorm. When excess water runs through the pile, the "flushout" phenomenon occurs,1/ i.e., acid and salt dissolve in the storm water and runoff into nearby surface waters. Thus, stream water quality can be severely deteriorated as a result of heavy rainfall in mining areas.

In addition to the flushout of pyritic oxidation products, rainfall and its subsequent runoff create fresh surfaces in the piles. The fresh surface permits the regeneration of oxidation products until the next rain, at which time the flushout process is repeated. Thus, waste piles are continuous "chemical factories" for the production of mine drainage.50/

In hard rock mining areas, tailings piles are often located on fractured rock which is inadequately sealed. Thus, water percolating through tailings piles can dissolve residual salts and be transmitted into groundwater supplies through the fractures or into surface waters as springs at the foot of the pile. The severity of the problem hinges on the adequacy of water supply at the processing site. If process water is abundant, then it can be wasted along with tailings. If water is in short supply, then it must be conserved and reused in the mining operation.

Water associated with the mineral deposits in hard rock mining areas is often contaminated with heavy metals. For example, water in parts of Nevada contain arsenic arising from natural sources.[48] Indeed, many of the mineral lodes in the West were discovered by tracing water polluted by natural leaching of minerals.

Control of leachate pollution from tailings piles is often hampered by the desire to save tailings for future mineral extraction. In the concentration process, it is impossible to remove all of the mineral values. Therefore, some mining companies stockpile tailings in the expectation that they can be reprocessed economically in the future. As a result, some tailings piles have existed 50 years or more without adequate maintenance. Seals between the pond and bedrock have deteriorated, and piles have eroded by water and wind. Thus, the effort to conserve mineral values has created sources of pollution.

The disposal of tailings into creeks has resulted in sediment deposits from which chemicals can leach readily into groundwater and surface water supplies. The Homestake Mine discharges into the Whitehead Creek and Cheyenne River basins are a case in point.[24] These tailings contain mercury in the waste, since mercury is a reagent in the extraction of gold. Thus, toxic materials used in concentrating minerals can find their way into tailings and hence into water supplies.

(d) Radioactivity from mining operations: Radioactivity arising from mining activities is primarily a long-range concern in the western United States, especially with regard to increased mining activities and control of seepage of uranium and radium from mill tailings at sites where uranium ores are mined and processed. Although concentrations approximating the maximum permissible concentration limits (MPC_w) have been recorded in water systems excluded from general public use, in the majority of radioactive monitoring data, MPC_w limits for radionuclides in public water supplies have not been approached. The effects of very long-term exposure to low levels of radioactivity are not known, however.

Region VIII of the Environmental Protection Agency has conducted two studies concerned with disposal of radioactive tailings. Those studies are: Disposition and Control of Uranium Mill Tailings Piles in the Colorado River Basin,[27] and Environmental Evaluation of Mines Development, Inc., Uranium and Vanadium Milling Operations at Edgemont, South Dakota.[25] In both of those studies, the need for a conservative approach to tailings disposal was emphasized, even though permissible radiation levels were not exceeded.

A Radium Monitoring Network has been established in the Colorado River Basin.[23] In the several years that this network has been in operation no excessive amounts of radioactivity have been found in the water.

Radioactivity has been discovered in mine drainage in the Kiskiminetus River, a tributary of the Allegheny River in Pennsylvania.[7] Data clearly show that radioactive nuclides are present in mine drainage and in receiving waters downstream from the drainage source. The radioactivity increases are noted only in mining areas, indicating that the mining operations are responsible.

In many coals, uranium is a trace metal associated with the coal. In Western Pennsylvanian coals, uranium contents range from 10 to 140 ppm. In eastern Pennsylvania, some coal deposits contain up to 3,000 ppm (0.3%) of uranium oxide, U_3O_8.

While there is limited information available on Western coals, it is known that there is uranium present. Because of peculiarities of Western coal, uranium and the other constituents may be of some environmental consequence.

(e) Nutrient and pesticide pollution from mined land reclamation: Effective reclamation of land disturbed by mining activities requires usage of fertilizers and pesticides to promote vegetative stabilization. These materials are potential pollutants, to an extent governed chiefly by the care exercised in their use.

(f) Subsidence from abandoned underground mines: A special environmental aspect of mining operations is subsidence in abandoned underground mining areas. Subsidence is the caving-in of abandoned underground excavations resulting in instability of ground overlying the excavation. In many parts of the country, usage of land over undermined areas is hindered because of subsidence.

A compilation of areas of the country where mine subsidence exists is shown in Table 5-2. This table has been entered into the record of hearings concerning surface mining legislation held before the U.S. Senate Subcommittee on Minerals, Materials, and Fuels of the Committee on Interior and Insular Affairs, 92nd Congress, First Session.[31]

TABLE 5-2

UNDERGROUND MINES IN URBAN AREAS[31]

Alabama	Coal and iron mines: adjacent to Birmingham
Arizona	Copper mines: Bisbee and Jerome
Arkansas	Coal mines: Hartford, Montana, Paris and Spadra
Colorado	Coal mines: Decona, Firestone, Frederick, Lafayette and Louisville Lead-zinc mines: Leadville
Idaho	Coal, silver, lead and zinc mines: Burke, Gem, Kellogg, Mullan, Murray and Smelterville
Illinois	Portions of cities and towns probably underlain by mines include: Belleville, Carbondale, Centralia, Danville, Decatur, Harrisburg, Herrin, Johnston City, Marion, Mount Vernon, Springfield, West Frankfort and Zeigler Lead-zinc mines underlie Galena
Indiana	Coal mines: Ashboro, Augusta, Boonville, Brazil, Carbon, Centerpoint, Chandler, Dugger, Evansville, Fort Branch, Francisco, Gibson, Hymera, Kings, Knightsville, Linton, Newburgh, New Goshen, Petersburg, Seelyville and Yankeetown
Iowa	Coal mines: Boone, Centerville, Des Moines, Knoxville, Oskaloosa and Ottumwa
Kansas	Zinc-lead mines: Galena and Treece Limestone mines: Kansas City Coal mines: Alma, Atchison, Burlingame, Cherokee, Croveburg, Franklin, Frontenac, Lansing, Leavenworth, Mineral, Mulberry, Osage City, Pittsburg, Pleasanton, Scammon, Scranton, Weir and Williamsburg Salt mines: Hutchinson, Kanopolis, and Lyons
Kentucky	Coal mines: Madisonville limestone mines: Lexington

TABLE 5-2 (Continued)

Maryland	Dimension stone mines: Cardiff Coal mines: Frostburg
Michigan	Iron mines: Bessemer, Iron River, Ironwood, Ishpeming, Negaunee and Wakefield Salt mines: Detroit Gypsum mines: may be under Grand Rapids Copper mines: adjacent to and probably underneath Calumet, Hancock and Houghton
Minnesota	Iron mines: Aurora, Biwabik, Chisholm, Eveleth, Hibbing and Keewatin
Missouri	Zinc-lead mines: Alba, Aura, Caterville, Duenweg, Neck City, Oronoga, Purcell, Webb City and Wentworth Lead mines: Annapolis, Boone Terre, Desloge, Doe Run, Flat River, Leadington, Leadwood, Valles Mines and Viburnum Coal mines: Bevier, Brookfield, Bucklin, Gainesville, Cameron, Carrollton, Clifton Hill, Deepwater, Elmira, Farber, Huntsville, Kansas City, Kingston, Kirkville, Knoxville, Lexington, Macon, Marceline, Melbourne, Milan, Mindenmines, Missouri City, Montgomery City, New Cambria, Richmond, St. Louis, Trenton, Vibbard, Waverly, Wellington, Windsor and Winston Clay mines: Deppwater and St. Louis Limestone mines: Carthage, Kansas City and Neosho Sandstone mines: Crystal City
Montana	Copper mines: Butte, Centerville and Walkerville
Nevada	Gold and silver mines: Tonepah and Virginia City
New Jersey	Iron mines: Dover, Hibernia, Mine Hill, Ringwood, Rockaway and Wharton
New York	Iron mines: Lyon Mountain, Mineville and Witherbee
Ohio	Coal mines: may underlie some urban areas in the southeastern portion of the State Salt mines: Cleveland

TABLE 5-2 (Continued)

Oklahoma	Coal mines: Bokoshe, Broken Arrow, Coalgate, Coalton, Cottonwood, Dewar, Haileyville, Hartshorne, Henryetta, Krebs, Lehigh, McAlester, McCurtain, Tulsa and Wilburton Zinc-lead mines: Cardin, Commerce, North Miami, Peoria, Picher and Quapaw
Oregon	Coal mines: Coos Bay Iron mines: Oswego
Pennsylvania	Anthracite mines: The Anthracite region and particularly the northern Anthracite field including Scranton and Wilkes-Barre Bituminous mines, portion of the following urban areas are undermined: Brownsville, Cannonsburg, Charleroi, Donora, Metropolitan Pittsburgh, Monongahela and Uniontown
South Dakota	Gold mines: Lead
Virginia	Gypsum mines: Plasterco Coal mines: Norton
Washington	Coal mines: Bellingham, Black Diamond, Carbonado, Centralia, Chehalis, Cle Elum, Issaquah, Newcastle, Ravensdale, Renton, Ronald, Roslyn and Wilkeson Iron mines: Hamilton Gold mines: Chewelah, Republic and Wenatchee Lead-zinc-silver mines: Leadpoint and Metaline
West Virginia	Coal mines: Barrackville, Bartley, Bradshaw, Fairmont, Fairview, Farmington, Grant Town, Monongah, Rivesville and Welch
Wisconsin	Lead-zinc mines: Benton, Hazel Green, Mineral Point, New Diggings, Platteville, Shullsburg and Tennyson Iron mines: Hurley and Montreal
Wyoming	Coal mines: Reliance and Rock Springs

TABLE 5-2 (Concluded)

"Based on the incidence of subsidence in the past, it is estimated that because of existing instability, some 750,000 surface areas of the remaining undermined 6 million acres will have been affected by subsidence by the year 2000. The amount of land that is expected to subside as a result of mining beneath an additional 5 million acres over the 1966-2000 period is 1,720,000 acres. The estimated total subsidence expected to occur between 1966 and the year 2000 therefore amounts to about 2.5 million acres. Remedial action to lessen subsidence incidents through backfilling and improved support techniques during actual mining operations in the future would tend to reduce the potential."

5.2.4 Sources of mining-related pollution: Pollution from mining activities can arise from several sources. It can come from active mining operations with inadequate controls; from inactive mining operations improperly shutdown or abandoned with no attempt at reclamation; or from the unique set of conditions peculiar to the geography and climate adjacent to the mining operation. In addition, the nature and extent of the pollution from mining depends upon the particular mineral deposit, the type of mining used to extract the mineral, and the length of time that the particular deposit has been mined. The mining operation (surface versus underground) and the age of the mining activity are primary considerations in assessing the nature and extent of pollution.

The most noted sources of pollution from mining are those associated with coal. Coal has been the primary energy source in the United States for many years, as reflected in coal production statistics. Since 1920, approximately 23 billion metric tons (25 billion tons) of bituminous coal and 2.2 billion metric tons (2.4 billion tons) of anthracite coal have been mined.42/ In 1971, over 500 million metric tons (550 million tons) of bituminous coal were mined; 46.9% was obtained through surface mining methods, 3.1% by auger methods, and 50.0% by underground methods. The tonnage of coal mined annually will undoubtedly increase in the future, especially since resources of other fossil fuels (petroleum and natural gas) are becoming increasingly limited.

The coal mining pollution problems have been extensively characterized for the Appalachian Region of the United States. The Appalachian Regional Commission has published a six-volume report on mine drainage4/ in which a very detailed account of the nature of mine drainage and its effect upon the economy of Appalachia are presented. While this report deals specifically with one problem in a specific area, it is of general interest as an outline of the data inputs needed in any study to establish environmental consequences of mining operations.

In recent years, demands for clear air have created increased mining activity in low-sulfur coal deposits in the Northern Great Plains (Wyoming and Montana). The pollution problems associated with coal mining in the western United States have not been extensively characterized. However, any pollution arising from these operations will be considerably different from the problems found in Appalachia. The deposits are low in sulfur; hence, they should be less prone to generate acid mine drainage. The deposits are located in a semi-arid region; hence, less water is available for transporting pollutant away from the operation. On the other hand, the mining of Western coal deposits may adversely affect local groundwater, the principal source of fresh water in the region.

This section will present details of some mine drainage pollution problems in Appalachia. In addition, the following pollution sources will be discussed in less detail: hard rock minerals; stone, sand, and gravel; noncoal sedimentary minerals; and oil and gas.

(a) Coal mine drainage in Appalachia: An accurate assessment of mine drainage sources in Appalachia is difficult, since the sources are constantly changing. The coal mining industry is taking steps to improve mining operations in order to minimize pollution potential in active mines, and together with governmental agencies (federal, state, and local) is engaged in activities to stem pollution from inactive and abandoned mining sources. As a result, the nature and extent of the coal mine drainage problem in Appalachia constantly shifts from year to year.

The following discussion is based upon sets of data which are less than 5 years old, but are already considered to be outdated. The data are presented because of the depth and completeness, and because they illustrate problems encountered in characterizing mine-related pollution so that planning can be initiated. The methodology used in Appalachia may be useful to responsible persons in other parts of the country where mining pollution is less well characterized.

In the Appalachian Region, mine drainage emissions have not been noted at many coal mining operations. The volume of mine drainage emitted by active and inactive operations varies widely from mine to mine and from watershed to watershed. Tybout[51] has listed the number of bituminous coal mines in 32 Pennsylvania coal producing counties, and has totaled the amount of drainage coming from several sources in each county. This tabulation is presented as Table 5-3. The tabulation shows that 2,300 of 4,716 underground mines and 3,613 of the 8,246 surface mines reported mine drainage.

Another important feature of Table 5-3 is the number of mines with "unknown" drainage. An unknown source in Table 5-3 refers to a mine for which no drainage data were available during Tybout's survey. Of the 4,716 underground mines, drainage data for 999 mines were "unknown." Drainage for surface mines was less well defined; 1,892 surface mines out of a total of 8,246 had no information concerning drainage.

TABLE 5-1

PENNSYLVANIA BITUMINOUS MINING DRAINAGE CASES[51]*

	Number of Mines					Volume of Mine Drainage (megaliters per day)		
	Draining Mines							
County	Active	Inactive	No Drainage	Unknown[a]	Total	Active	Inactive, Extrapolated[b]	Total
Underground Mines:								
Allegheny	39	54	11	75	179	183	84	267
Armstrong	55	145	115	25	340	6.8	21	27.8
Beaver	2	5	23	6	36	0.04	0.27	0.31
Bedford	7	8	45	16	76	0.29	0.80	1.09
Blair	0	1	6	11	18	0	0.16	0.16
Bradford	2	4	0	1	7	0	0	0
Butler	16	42	87	32	177	20	7.8	27.8
Cambria	49	104	200	206	559	81	142	223
Cameron	0	1	0	3	4	0	0	0
Centre	7	30	[illegible]	15	74	3.9	1.3	5.2
Clarion	5	23	100	22	150	0.06	2.2	2.26
Clearfield	37	68	274	117	496	5.3	19	24.3
Clinton	0	1	11	12	24	0	0.06	0.06
Elk	7	7	49	21	84	0.43	2.3	2.73
Fayette	10	96	59	75	240	0.03	88	88.03
Forrest	0	0	0	1	1	0	0	0
Fulton	0	0	0	1	1	0	0	0
Greene	68	71	44	23	206	57	33	90
Huntington	0	2	33	8	43	0	2.6	2.6
Indiana	57	97	366	48	568	69	42	111
Jefferson	27	79	236	11	353	7.4	50	57.4
Lawrence	0	5	11	3	19	0	4.5	4.5
Lycoming	0	0	5	5	10	0	0	0
McKean	0	1	0	2	3	0	0	0
Mercer	0	1	15	4	20	0	0	0
Potter	0	0	0	0	0	0	0	0
Somerset	36	40	312	123	511	0.69	77	77.69
Sullivan	0	0	3	1	4	0	0	0
Tioga	1	5	16	3	25	0.51	7.9	8.41
Venango	1	1	3	4	9	0	0	0
Washington	36	21	48	44	149	32	52	84
Westmoreland	15	8	226	81	330	81	21	102
Total Underground	477	940	2,300	999	4,716	548.45	658.89	1,207.34

TABLE 5-1 (Concluded)

County	Number of Mines: Draining Mines: Active	Number of Mines: Draining Mines: Inactive	Number of Mines: No Drainage	Number of Mines: Unknown[a]	Number of Mines: Total	Volume of Mine Drainage (megaliters per day): Active	Volume of Mine Drainage (megaliters per day): Inactive, Extrapolated[b]	Volume of Mine Drainage (megaliters per day): Total
Strip Mines								
Allegheny	6	5	113	125	249	0.03	0.94	0.97
Armstrong	37	57	240	307	641	0.69	4.6	5.29
Beaver	3	17	48	62	130	0.01	1.3	1.31
Bedford	1	2	10	22	35	0.02	0	0.02
Blair	1	0	7	7	15	0	0	0
Bradford	3	1	6	0	10	0.02	0	0.02
Butler	24	136	338	297	795	2.0	37	39.0
Cambria	12	4	114	117	247	0.61	0	0.61
Cameron	1	6	5	6	18	0	0	0
Centre	17	7	54	64	142	0.89	0.60	1.49
Clarion	15	31	418	527	991	0.32	4.9	5.22
Clearfield	26	53	521	665	1,265	1.4	6.4	7.8
Clinton	3	4	37	19	63	0.12	0.42	0.54
Elk	3	7	90	41	141	0.14	0.33	0.47
Fayette	0	7	121	217	345	0	3.7	3.7
Forrest	0	0	3	1	4	0	0	0
Fulton	0	0	0	2	2	0	0	0
Greene	0	0	22	35	57	0	0	0
Huntington	0	0	16	28	44	0	0	0
Indiana	16	6	192	199	413	0.76	1.4	2.16
Jefferson	16	33	325	270	644	0.48	2.3	2.78
Lawrence	23	21	126	105	275	2.2	5.1	7.3
Lycoming	6	1	3	2	12	0.16	0.02	0.18
McKean	1	10	7	11	29	0.02	2.8	2.82
Mercer	16	9	57	59	141	3.7	2.7	6.4
Potter	0	0	0	3	3	0	0	0
Somerset	13	21	348	329	711	1.0	2.6	3.6
Sullivan	0	0	4	4	8	0	0	0
Tioga	0	3	17	15	35	0	4.7	4.7
Venango	13	33	102	79	227	1.2	7.7	8.9
Washington	3	3	89	88	183	0.01	0.06	0.07
Westmoreland	2	3	180	186	371	< 0.01	0.17	0.18
Total Strip	261	480	3,613	3,892	8,246	15.79	89.74	105.53
Total Mines	738	1,420	5,913	4,891	12,962	564.24	748.63	1,312.87

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[a] Unknown refers to inactive mines having no drainage data recorded at time of survey (1965).

[b] Extrapolated inactive mine drainage data includes all "unknown" mines as inactive mines.

Note: Adapted (from Ref. 31).

Since the "unknown" mines were assumed to be emitting mine drainage at the same rate as inactive mines in the particular county, the absolute accuracy of the mine drainage volumes attributed to inactive mines may be questioned. Nevertheless, the information is a valid base for assessment, planning, and implementation of remedial action since 1968. Progress between 1968 and 1973 has defined the situation more clearly, and updated data for the Pennsylvania bituminous coal producing counties could be very different.

The Appalachian Regional Commission report entitled Acid Mine Drainage in Appalachia[4/] has addressed mine drainage sources from a different direction. This report contains data on the amount of acidity emitted to various watersheds based upon known drainage sources in specific watersheds in Northern Appalachia. The Appalachian Regional Commission data are presented in Table 5-4.

The data shown in Table 5-4 represent known mine drainage sources. Thus, the total number of sources included in the study is less than the total number of active and inactive mines in the region. The acid emitted by active and inactive mines in various parts of Northern Appalachia varies, as shown by Table 5-4, markedly from one watershed to another. The high degree of variance makes it difficult to define a "typical" mine drainage source, and indicates that the nature and extent of mine drainage is quite dependent upon local geographical and geological conditions.

Since publication of the Appalachian Regional Commission report on mine drainage, many of the mine drainage sources have been and are being brought under control. A current compilation of data would be quite different than the 1969 compilation. Studies of the type conducted by the Appalachian Regional Commission, thus serve to define specific localities with mine drainage problems, provide a quantitative basis for planning, and provide a yardstick for measuring progress toward elimination of problem areas.

(b) Hard rock minerals: Hard rock mining is extensive in the western United States. Ores obtained from hard rock mining areas are usually associated with pyrite, hence the mining operations are potential producers of acid similar to that from coal operations. In addition to ordinary pyritic materials, the hard rock ores are associated with heavy metals, so that the acid formed can contain significant quantities of toxic metals. In the Central Rocky Mountains, the elements copper, zinc, and arsenic are almost always associated with mine drainage. In the Central City region of Colorado, streams draining abandoned workings can contain up to 5 mg/liter of copper, 5 mg/liter of zinc, and 2 mg/liter of arsenic.[45/] The copper and

TABLE 5-6

SELECTED INFORMATION FOR ACID MINE DRAINAGE SOURCES IN NORTHERN APPALACHIA[a]*

Subarea	Underground		Surface		Combined[b]		Other Sources[c]		Total	
	Sources	Acidity[a]	Sources	Acidity	Sources	Acidity	Sources	Acidity	Sources	Acidity
Active Mining Operations										
Anthracite Area										
Susquehanna Basin	36	47,450	--	--	--	--	--	--	36	47,450
Delaware Basin	4	1,040	--	--	--	--	--	--	4	1,040
Tioga River	--	--	--	--	--	--	--	--	--	--
West Branch Susquehanna	19	4,770	17	930	--	--	--	--	36	5,700
Juniata River	--	--	--	--	--	--	--	--	--	--
Allegheny River										
Clarion River	4	50	3	480	1	120	1	22	9	672
Kiskiminetas River	31	54,450	5	190	--	--	1	31	37	54,671
Monongahela River	175	121,400	49	8,950	23	22,500	23	2,190	270	155,040
Ohio River Tributaries										
Wheeling Creek	2	51	--	--	--	--	--	--	2	51
Raccoon Creek	--	--	1	31	--	--	1	324	2	355
Capatina Creek	7	-129	--	--	--	--	2	2,380	9	2,251
Total Active Sources Inventoried	278	229,082	75	10,581	24	22,620	28	4,947	405	267,230
Inactive Mining Operations										
Anthracite Area										
Susquehanna Basin	73	144,500	3	336	--	--	1	37	77	144,873
Delaware Basin	41	9,440	3	112	--	--	--	--	44	9,552
Tioga River	15	8,100	7	900	--	--	--	--	22	9,000
West Branch Susquehanna	560	99,400	267	39,020	--	--	104	41,960	931	180,380
Juniata River	44	14,140	--	--	--	--	--	--	44	14,140
Allegheny River										
Clarion River	145	12,380	240	34,360	57	7,000	40	2,650	482	56,390
Kiskiminetas River	381	158,100	155	4,930	107	9,730	84	38,180	727	210,940
Monongahela River	1,619	168,900	749	43,360	249	41,500	8	3,350	2,625	257,090
Ohio River Tributaries										
Wheeling Creek	41	1,990	12	288	16	2,830	1	49	70	5,157
Raccoon Creek	31	21,350	69	11,230	39	27,660	1	23	140	60,263
Capatina Creek	3	50	--	--	--	--	--	--	3	50
Total Inactive Sources Inventoried	2,953	638,350	1,505	134,716	468	88,720	239	86,249	5,165	948,035
Total Sources Inventoried	3,231	867,432	1,580	145,297	492	111,340	267	91,196	5,570	1,215,265

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[a] Acidity is measured as net acidity in kilograms of $CaCO_3$ equivalent per day.

[b] Combined sources are those sources including both surface and underground mines.

[c] Other sources are primarily coal processing plants in active mines and mining refuse piles for inactive mines.

* Note: Adapted (from Ref. 4).

General Notes: This information includes virtually all of the source inventory data obtained by FWPCA for the region during 1966-1969. The FWPCA has estimated that the areal coverage accounts for 75% of the acid mine drainage formed in the region. The number of sources shown represents that portion of the identified mine sites which were producing mine drainage at the time of inventory. Since most sites were inventoried during the summer, the sources do not include those which are seasonal. There appears to be many more mine sites than identified sources. For instance, the Monongahela Basin inventory identified over 7,000 mine sites, but only 2,895 were producing mine drainage when surveyed.

arsenic levels are higher than permissible surface water criteria (1.0 mg/liter of copper and 0.05 mg/liter of arsenic) for public water supplies. In addition to copper, zinc, and arsenic, some hard rock mining areas will add lead, antimony, cadmium, mercury, and other heavy metals to water supplies.

Mining sources in the San Juan Mountains of Colorado have been identified with respect to their contribution to the salinity of the Colorado River.[6] It was found that mine drainage contributes approximately 18 metric tons (20 tons) daily of dissolved solids to the Dolores and San Miguel rivers, and ultimately to the Colorado River. Springs and salt seeps in the area emit about 630 metric tons (695 tons) of salt per day to the Colorado River Basin. Summaries of the San Juan Mountain mine drainage sources are available for review in the Environmental Protection Agency Region VIII Offices in Denver, Colorado.[6]

A study now being conducted in Colorado concerns "Effects of Mining on Surface Water Quality Exclusive of Uranium Mining in Colorado."[69] This study is being conducted for the State of Colorado by the Water Resources Division (Colorado Division) of the U.S. Geological Survey. This study will be used to identify streams which are affected by mining operations in Colorado, and suggest monitoring sites for continued data acquisition. The Colorado study, when it is published, should serve as a model for other states in recognizing the sources and types of stream pollution arising from mining operations.

A third study, entitled "Water Quality Considerations for the Metal Mining Industry in the Pacific Northwest",[47] was chiefly concerned with water pollution at active and abandoned mines. The report presents suggestions and recommendations for minimizing the effects of mining on water quality. This study addresses itself specifically to mine problems in Region X of the Environmental Protection Agency.

Hard rock mining activities located above the timber line in the western United States have unique pollution problems, since it is very difficult to restore disturbed land where natural conditions do not promote rapid revegetation. In addition, mine-related activities such as haul roads tend to create more serious pollutant-generating conditions than similar activities at lower elevations. The pollution generated from mining activities above the timber line is being investigated at Goose Creek, Montana, by Region VIII of the Environmental Protection Agency.[32]

The problems associated with sediment discharges from the Homestake Mine (gold) in Lead, South Dakota,[24] and their deposition in the Cheyenne River Valley have been discussed briefly earlier (Section 5.2.3a, c).

(c) Stone, sand and gravel: The production of stone, sand, and gravel constitutes the largest volume of materials from mining activities in the United States. In 1971, 792 million metric tons (873 million tons) of stone were quarried, and 884 million metric tons (920 million tons) of sand and gravel were dredged.[54] This tonnage is 39% of all mined materials in 1971.

Definitive information concerning the pollution from stone, sand, and gravel operations is not readily available. Evaluation of the pollution potential from dredging operations (the common technique used to mine sand and gravel) has been conducted in a study which parallels the study reported in the present document.

(d) Noncoal sedimentary mineral operations: In addition to coal, several other sedimentary minerals are mined in the United States. Important products include clay, phosphate rock, iron ore, and uranium. These products are usually mined by surface methods, and hence are potential sources of sediment. The nature of the operations is such, however, that sediment is controlled at the mining site. The quantity of waste material generated by ore concentration processes is usually much greater than the mineral values recovered. Thus, a major operational problem lies in the management of the wastes. In the case of phosphate rock, 1-1/4 hectares (acre) of land is required to contain the waste from 1 hectare (acre) of mined rock.[14]

As has been discussed in Section 5.2.3, disposal of uranium tailings is a possible source of radioactivity in water supplies.

(e) Oil and gas: Abandoned oil and gas wells are contributors of salinity to water supplies. The discharges often arise from inadequate sealing, or from seal deterioration over the years.

Oil and saltwater discharges observed[49] from the El Dorado Oil Field in Central Kansas illustrate the general nature of this problem. During a 3-month period in 1971, eight salt springs arising from abandoned oil wells erupted along a 3-mile stretch of a stream. These eruptions were apparently caused by two factors. First, hydraulic pressure is being applied to the field in order to recover oil values; weak seals on abandoned wells can thus rupture and discharge salt water. Second, several salt springs from abandoned oil wells on adjacent properties were resealed; the resealing resulted in a change of the local hydraulic pressures, and permitted new leaks to occur at the weakest points.

Saline water seeps in the vicinity of Meeker, Colorado, were noted in 1970.[26] This area contains several wells drilled intermittently since 1915 for oil exploration purposes. The seepage was of special concern, since it occurred less than 2 years after wells in the area had been plugged. It was concluded that "plugging of all wells that intercepted aquifers has removed the artifical pressure relief channels formed by the unplugged wells such that natural saline groundwater is again under sufficient pressure to force it to the surface through natural fractures in a manner similar to that existing prior to the drilling. Replugging the wells will not achieve a reduction in seepage if these fractures intercept the aquifers as they appear to do."

5.2.5 Statistics for mining activities: The nature and extent of pollution sources from mining will constantly change as old mineral deposits are worked out and new mineral deposits are opened. This section presents statistical information on inactive and abandoned mines, and sources of current statistics on active mining operations.

(a) Inactive and abandoned mines: The number of inactive and abandoned underground mines has been listed (Table 5-5) in an unpublished U.S. Bureau of Mines study[53] concerning environmental effects of underground mining. Pollution outputs from those inactive and abandoned mines is unknown. It is known that many abandoned underground mines in Northern Appalachia do not emit mine drainage (see Section 5.2.4, Table 5-3).

This list is incomplete, especially regarding abandoned mines in the western United States. Throughout the West, many prospector pits have been dug which never yielded valuable minerals. These pits have been abandoned, and have left holes in the ground with adjacent piles of rock spoil. It is estimated that there are over 10,000 abandoned prospector pits in Colorado alone.[45]

Inactive and abandoned surface mining operations are also sources of pollution. The U.S. Department of the Interior concluded an extensive study, in the mid-1960's, of pollution arising from surface mining.[55] The report contains statistics (as of 1965) pertaining to land disturbed as a result of various surface mining operation in the United States. A list of disturbed land acreage by commodity and state presented in their report is reproduced as Table 5-6.

TABLE 5-5

ABANDONED AND INACTIVE UNDERGROUND MINES IN THE UNITED STATES AS OF 1966[53]

State	Coal	Metal	Nonmetal
Alabama	310	64	27
Alaska	6	--	--
Arizona	--	773	6
Arkansas	269	186	--
California	32	3,045	82
Colorado	565	1,699	7
Connecticut	--	6	3
Delaware	--	--	--
Florida	--	--	--
Georgia	115	62	28
Hawaii	--	--	--
Idaho	11	1,749	208
Illinois	1,605	39	124
Indiana	960	--	2
Iowa	1,138	60	--
Kansas	528	681	13
Kentucky	12,045	4	120
Louisiana	--	--	1
Maine	--	7	--
Maryland	564	7	--
Massachusetts	--	7	1
Michigan	--	278	6
Minnesota	--	87	--
Mississippi	1	--	1
Missouri	466	1,520	36
Montana	334	1,691	146
Nebraska	--	--	--
Nevada	5	1,346	10
New Hampshire	--	24	3
New Jersey	--	26	--
New Mexico	48	277	23
New York	--	61	17
North Carolina	5	78	1,129
North Dakota	--	12	--
Ohio	2,187	35	53
Oklahoma	251	283	--
Oregon	61	1,140	3
Pennsylvania	7,824	160	55
Rhode Island	--	2	4
South Carolina	--	30	17
South Dakota	1	172	--
Tennessee	2,931	42	11
Texas	21	31	--
Utah	44	1,348	8
Vermont	--	17	3
Virginia	14,397	14	6
Washington	247	907	52
West Virginia	20,616	--	9
Wisconsin	--	389	1
Wyoming	26	295	--
Total	67,613	18,654	2,215

TABLE 5-6

LAND DISTURBED BY STRIP AND SURFACE MINING IN THE UNITED STATES AS OF JANUARY 1, 1965, BY COMMODITY AND STATE[55]

(Acres)

State	Clay	Coal (Bituminous, Lignite and Anthracite)	Stone	Sand and Gravel	Gold	Phosphate Rock	Iron Ore	All Other	Total
Alabama[a]	4,000	50,600	3,900	21,200	100	--	52,600	1,500	133,900
Alaska[b]	--	500	--	2,000	8,600	--	--	--	11,100
Arizona[a]	2,700	--	1,000	7,200	1,200	--	--	20,300	32,400
Arkansas[b]	600	10,100	900	2,600	--	--	100	8,100	22,400
California[b]	2,700	20	8,000	19,900	134,000	--	900	8,500	174,020
Colorado[a]	2,000	2,800	6,200	15,500	17,100	--	25	11,400	55,025
Connecticut[a]	--	--	100	16,100	--	--	--	100	16,300
Delaware[b]	200	--	200	5,200	--	--	100	10	5,710
Florida[a]	13,200	--	25,300	3,900	--	143,600	--	2,800	188,800
Georgia	1,300[c]	300[c]	6,800[c]	1,200[c]	--	--	100[c]	12,000[c]	21,700[a]
Hawaii[b]	--	--	--	--	--	--	--	10	10
Idaho[b]	500	--	700	11,200	21,200	3,100	35	4,200	40,935
Illinois[b]	1,400	127,000	5,700	9,000	--	--	--	--	143,100
Indiana[b]	1,500	95,200	10,200	18,000	--	--	--	400	125,300
Iowa[a]	1,300	11,000	12,200	17,600	--	--	6	2,300	44,406
Kansas	1,100[a]	45,600[b]	7,500[a]	5,100[a]	--	--	--	200[a]	59,500
Kentucky	2,400[a,b]	119,200[a,b]	3,900[a]	1,700[a]	--	--	--	500[a]	127,700
Louisiana[a]	900	--	100	29,700	--	--	50	--	30,750
Maine[a]	400	--	4,400	28,200	12	--	100	1,700	34,812
Maryland	1,200[a,b]	2,200[b]	2,200[a]	18,800[a]	--	--	20[a]	800[a]	25,220
Massachusetts[a]	700	--	1,200	36,400	--	--	1,100	900	40,300
Michigan[b]	600	--	7,700	25,200	--	--	2,200	1,200	36,900
Minnesota[a]	600	--	3,900	41,600	3	--	67,700	1,600	115,403
Mississippi[b]	2,700	--	400	26,500	--	--	30	--	29,630
Missouri[b]	6,600	31,800	8,400	3,800	--	--	200	8,300	59,100
Montana[b]	--	1,500	10	13,500[c]	5,600	100	10	6,200	26,920
Nebraska[b]	900	--	4,300	23,700	--	--	--	--	28,900
Nevada[a]	100	--	1,600	5,500	5,600	--	600	19,500	32,900
New Hampshire[b]	--	--	100	8,000	--	--	--	200	8,300
New Jersey[b]	1,400	--	2,000	27,600	--	--	1,000	1,800	33,800
New Mexico[b]	13	1,200	100	400	40	--	100	4,600	6,453
New York[a]	1,700	--	12,500	42,200	5	--	700	600	57,705
North Carolina[a]	5,800	10	6,000	18,400	2,200	300	100	4,000	36,810
North Dakota	800[a]	7,700[b]	300[b]	26,100[a]	--	--	--	2,000[a]	36,900
Ohio	10,200[a]	212,800[b]	21,000[a]	28,100[a]	--	--	4,000[a]	600[a]	276,700
Oklahoma[b]	--	23,500	--	2,500[c]	--	--	--	1,400	27,400
Oregon[b]	100	--	300	1,300	6,300	--	10	1,400	9,410
Pennsylvania	10,400[a]	302,400[b]	24,400[a]	23,800[a]	2[a]	--	8,800[a]	400[a]	370,202
Rhode Island[a]	--	--	20	3,600	--	--	--	--	3,620
South Carolina[a]	10,900	--	1,400	10,400	200	8,100	100	1,600	32,700
South Dakota	2,000[b]	900[b]	--	28,000[c]	--	--	--	3,300[b]	34,200
Tennessee[b]	2,700	29,300	4,400	18,400	--	27,000	5,300	13,800	100,900
Texas[a]	6,800	2,900	21,900	122,300	--	-	9,600	2,800	166,300
Utah[b]	600	--	200	2,200	--	10	500	2,000	5,510
Vermont	--	--	2,300[b]	4,000[a]	--	--	--	400[b]	6,700
Virginia	1,100[a,b]	29,800[b]	4,300[a]	13,100[a]	600[a]	100[a]	7,700[a,b]	4,100[a,b]	60,800
Washington[b]	500	100	1,300	5,700	400	--	20	--	8,820
West Virginia[b]	300	192,000	2,800	300	--	--	100	--	195,500
Wisconsin[b]	100	--	9,000	26,400	5	--	49	--	35,554
Wyoming	3,500[a,b]	1,000[b]	300[a,b]	200[a,b]	--	800[b]	300[a,b]	4,300[b]	10,400
Total	108,513	1,301,430	241,430	823,300	203,167	183,110	164,255	162,620	3,187,825

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[a] Data obtained from Soil Conservation Service, U.S. Department of Agriculture.

[b] Data compiled from reports submitted by the States on U.S. Department of the Interior form 6-1385X.

[c] Estimate.

TABLE 5-6 (Concluded)

LAND DISTURBED BY STRIP AND SURFACE MINING IN THE UNITED STATES AS OF JANUARY 1, 1965, BY COMMODITY AND STATE

(Hectares)

State	Clay	Coal (Bituminous, Lignite and Anthracite)	Stone	Sand and Gravel	Gold	Phosphate Rock	Iron Ore	All Other	Total
Alabama	1,600	20,500	1,600	8,600	40	--	21,300	607	54,247
Alaska	-	200	--	810	3,500	--	--	--	4,510
Arizona	1,100	--	400	2,900	490	--	--	8,200	13,090
Arkansas	240	4,100	360	1,100	-	--	40	3,300	9,140
California	1,100	8	3,200	8,100	54,200	--	360	3,400	70,368
Colorado	800	1,130	2,500	6,300	6,900	--	10	4,600	22,240
Connecticut	--	--	40	6,500	--	--	--	40	6,580
Delaware	80	--	81	2,100	--	--	40	4	2,305
Florida	5,300	-	10,200	1,600	--	58,100	--	1,100	76,300
Georgia	530	120	2,800	490	--	--	40	4,900	8,800
Hawaii	--	--	--	--	--	--	--	4	4
Idaho	200	--	280	4,500	8,600	1,300	14	1,700	16,594
Illinois	570	51,400	2,310	3,600	--	-	--	-	57,880
Indiana	610	38,500	4,130	7,300	--	--	-	160	50,700
Iowa	530	4,500	4,900	7,100	--	--	2	930	17,962
Kansas	450	18,500	3,000	2,100	--	--	--	81	24,131
Kentucky	970	48,200	1,600	700	--	--	--	202	51,672
Louisiana	360	--	40	12,000	--	--	20	--	12,420
Maine	160	--	1,800	11,400	9	--	40	690	14,099
Maryland	490	890	890	7,600	--	--	8	320	10,198
Massachusetts	280	-	490	14,700	--	--	450	360	16,280
Michigan	240	--	3,100	10,200	--	--	890	490	14,920
Minnesota	240	--	1,600	16,800	1	--	27,400	650	46,691
Mississippi	1,100	--	160	10,700	--	--	12	--	11,972
Missouri	2,700	12,900	3,400	1,500	--	--	81	3,400	23,981
Montana	--	607	4	5,500	2,300	40	4	2,500	10,955
Nebraska	360	--	1,700	9,600	--	-	--	--	11,660
Nevada	40	--	650	2,200	2,300	--	240	7,900	13,330
New Hampshire	--	--	40	3,200	--	--	--	80	3,320
New Jersey	570	--	810	11,200	--	--	400	730	13,710
New Mexico	5	490	40	160	16	--	40	1,900	2,651
New York	690	--	5,060	17,200	2	--	280	240	23,472
North Carolina	2,300	4	2,400	7,400	890	120	40	1,600	14,754
North Dakota	320	3,100	120	10,600	--	--	--	810	14,950
Ohio	4,130	86,100	8,500	11,400	--	-	1,600	240	111,970
Oklahoma	--	9,500	--	1,010	--	--	--	570	11,080
Oregon	41	--	120	530	2,500	--	4	570	3,765
Pennsylvania	4,210	122,400	9,870	9,600	1	--	3,600	160	149,841
Rhode Island	--	--	8	1,500	--	--	--	--	1,508
South Carolina	4,410	--	570	4,200	81	3,300	40	650	13,251
South Dakota	810	360	--	11,300	--	--	--	1,300	13,770
Tennessee	1,090	11,900	1,800	7,400	--	10,900	2,100	5,600	40,790
Texas	2,800	1,200	8,900	49,500	--	--	3,900	1,130	67,430
Utah	240	--	81	890	--	4	202	810	2,227
Vermont	--	--	930	1,600	--	--	--	160	2,690
Virginia	450	12,100	1,700	5,300	240	40	3,100	1,700	24,630
Washington	200	40	530	2,300	160	--	8	--	3,238
West Virginia	120	77,700	1,100	120	--	--	40	--	79,080
Wisconsin	40	--	3,600	10,700	2	--	20	-	14,362
Wyoming	1,420	405	120	81	--	320	121	1,700	4,167
Total	43,896	526,854	97,534	333,191	82,232	74,124	66,446	65,488	1,289,765

A part of the area in Table 5-6 is that associated with active surface mining sites as well as inactive sites. The U.S. Department of the Interior study has subdivided the surface mining areas into land that does or does not require reclamation. Of the 1.29 million hectares of disturbed land, reclamation is needed for 830,000 hectares, while 460,000 hectares do not require reclamation.

(b) Current statistics on active mining operations: The pollution potential from current mining activities can be qualitatively estimated by considering specific factors of the mining industries. These factors include: the type of mineral being mined, the tonnage of mineral extracted, the type of mining method, and the location of the mining activity.

The U.S. Bureau of Mines annually publishes The Minerals Yearbook.[54] This volume is an extensive compilation of current data pertaining to mining activities. Data of interest to persons concerned with pollution from mining include:

1. Material handled at surface and underground mines, by commodity.

2. Material handled at surface and underground mines, by state.

3. Percent of crude ore and total material handled at surface and underground mines, by commodities.

4. Percent of crude ore and total material handled at surface and underground mines, by states.

5. Number of mines, by commodity and crude ore production.

6. Kind of surface mining operations, by commodities and states.

7. Mineral production in the United States, by commodity.

8. Mineral production in the United States, by states.

9. Minerals produced in the United States and principal producing states.

In many cases, the current data can be used to determine trends in mineral production by comparison with corresponding data for preceding years. These comparative data are helpful in assessing the magnitude of active mining operations.

For the specific case of coal, the National Coal Association annually publishes Bituminous Coal Facts.42/ This report contains extensive data on current coal production as well as historical data for the past 50 years.

5.2.6 Pollution from modern mining operations: As implied throughout this discussion, it is unrealistic to assume that pollution from mining activities can be completely eliminated. However, it is realistic to expect that pollution can be markedly reduced.

(a) Mined land reclamation: Land reclaimed from mining operations remains a potential source of pollution, even though the reclaimed land may be used for other activities such as agriculture, silviculture, or recreation. Materials potentially capable of creating pollution are still present in the area, and indiscriminate use of the reclaimed land may undo the reclamation operation. It has been noted in some cases that the premature plowing of reclaimed land has exposed buried toxic material. This exposure resulted in plant toxicity, together with renewed acid and sediment production. Thus, time is required to reestablish an equilibrium in the environment.

The reclamation of land usually requires extensive use of fertilizers to create soil conditions such that vegetation can prosper. In some cases, limestone may be necessary to reduce acid generating potential in reclaimed land, and irrigation may be necessary to provide sufficient water for rapid vegetation cover. In most reclamation operations, the principal objective is to establish adequate vegetation cover in order to minimize sediment transport to local streams and reservoirs. Thus, some pollution from reclaimed mined lands will be the same as that encountered in agricultural operations.

Reclamation of mined land can greatly alleviate the pollution problems associated with mining. For the specific case of surface mining for coal, the environmental consequences of the mining operation have been estimated and compared with the effects resulting from mined land reclamation operations.16/ These effects are presented in Table 5-7. The ratings in the table have been divided into two categories: (1) effects of surface mining operations, and (2). effects of the reclamation operation. A plus (+) rating means that a specific adverse environmental effect is aggravated; a negative (-) rating implies that the adverse effect can be corrected. It is clear that the mining operation per se creates tremendous damage to the

TABLE 5-7

RATING OF ENVIRONMENTAL EFFECTS OF DISCRETE COAL SURFACE MINING AND RECLAMATION OPERATIONS[16/]*

	Environmental Component															
	Physical-Chemical											Biological		Cultural		
	Landslides	Slumping	Highwall	Erosion	Sediment Transport	Chemical Pollution	Changed Water Courses	Flooding	Groundwater Disruption	Dust	Noise	Ground Cover Destruction	Wildlife Pattern Disruption	Precluded Land Use	Adjacent Land Use	Aesthetic Deterioration
Surface Mining Operation																
1. Access road cut and use	+	+	0	+	+	+	+	0	0	+	0	+	0	0	+	0
2. Drilling and blasting	+	+	+	0	0	0	+	0	+	+	+	+	+	+	+	+
3. Scalping	0	0	0	+	+	0	0	+	0	+	0	+	+	0	0	+
4. Overburden removal and placement	+	+	+	+	+	+	+	+	+	+	0	+	+	+	+	+
5. Coal removal	0	0	+	+	+	+	0	0	0	+	0	0	0	0	0	0
Net Environmental Effect of Surface Mining Operation	3+	3+	3+	4+	4+	3+	3+	2+	2+	5+	1+	4+	3+	2+	3+	3+
Reclamation Operation																
6. Spoil rehandling and grading	-	-	-	-	-	-	-	-	0	+	0	0	-	0	-	-
7. Revegetation	-	-	0	-	-	0	0	-	0	-	0	-	-	-	-	-
8. Drainage controls	-	-	0	-	-	-	-	-	-	-	0	-	0	0	-	0
9. Sediment basin	0	0	0	0	-	0	0	-	0	0	0	0	0	0	-	0
Net Environmental Effect of Reclamation Operation	3-	3-	1-	3-	4-	2-	2-	4-	1-	1-	0	2-	2-	1-	4-	2-
Net Environmental Effect of Surface Mining And Reclamation Operation	0	0	2+	1+	0	1+	1+	2-	1+	4+	1+	2+	1+	1+	1-	1+

+ Adverse Environmental Impacts Aggravated
0 Negligible Environmental Impacts
- Adverse Environmental Impacts Corrected
* Adapted (from Ref. 16).

environment. However, the environment can generally be restored to usefulness with the application of good reclamation procedures. Indeed, two environmental components (flood control and adjacent land use) can be improved as a result of the mining operation.

It is clear, from Table 5-7, that active mining operations degrade all environmental components, but that these environmental components can often be restored by the reclamation operations. However, much of the pollution generated during the mining operation will have been dispersed before reclamation activities can begin. Thus, the real importance of reclamation operations is to prevent additional pollutants from being generated after mining has ceased.

Modern coal mining techniques have the potential of integrating mining and reclamation into a single system, in which the interval between the two operations is minimized--and pollutants emissions are likewise minimized.

(b) Future nonpolluting mining operations: The basic cause for pollution from mining activities in the country today stems from the fact that mineral resources have in the past been exploited without regard to environmental consequences. Compatibility between mining practices and environmental protection is probably best achieved by new and improved mining methods which do not create conditions which lead to pollution. Many such methods are being developed today.

New methods for the surface mining for coal have been detailed in a report by the Council on Environmental Quality to the U.S. Senate Committee on Interior and Insular Affairs.16/ This report contains an environmental and economic assessment of alternatives for coal surface mining and reclamation. Presented in the CEQ report is a table estimating the environmental effects of coal surface mining. This table is reproduced here as Table 5-8.

The ratings in this table are subjective. They are, nevertheless, realistic, and show clearly that surface mining integrated with reclamation can result in only minor environmental damage.

Future mining operations will be based upon the mining of the sea bottom to recover minerals. The extraction of minerals from the ocean floor has unknown pollution potential. It is known from land mining that any disturbance will affect the local ecology. Adverse effects on the marine ecology caused by ocean-floor mining are much less clearly understood than those associated with land-based mining.

TABLE 5-8

ESTIMATED ENVIRONMENTAL EFFECTS OF COAL SURFACE MINING[16]

(Scale for severity of environmental indicators:[a] 3 = Severe adverse impact; 0 = Negligible adverse impact)

Mining Technique[b]	Water			Air Pollution (Dust)	Land Use (Adjacent Land Impact and Precluded Land Use)	Health and Safety (Landslides and Flooding)	Wildlife Habitat and Disruption	Aesthetics (Highwall and Vegetation)	Total[c]
	Surface Pollution	Groundwater	Changed Water Courses						
Area Mining:									
Without reclamation	1-2	0-1	1-3	2-3	2-3	0	1-2	2-3	9-16
With reclamation[d]	0-1	0-1	0-1	1	0	0	0	0	1-4
Contour mining (spoils on downslope):									
Conventional contour strip	3	0-1	2-3	2-3	3	3	1-3	3	17-22
Contour strip with spoils shaping	1-3	0	2-3	2-3	2-3	1-3	1-2	2-3	11-20
Contour strip with terrace backfilling	1-2	0	0-2	1-2	1-2	1-2	1-2	0-1	4-13
Contour strip with contour backfilling	1	0	0-1	1-2	0-1	0-1	1	1	3-8
Augering from narrow bench	1-3	1-3	0-1	0-1	1-2	0-1	0-1	1	3-12
Contour mining (no spoils on downslope):									
Modified block cut	1	0	0	1	0	0	0-1	0-1	2-4
Long wall surface	0-1	1-2	0	0-1	0-1	0	0	0	1-5
Augering with backfilling	0-1	1-2	0	0-1	0	0	0	0	1-4

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[a] Indicators are for both temporary and pervasive impacts.

[b] Head of hollow fill technique is not rated here because its environmental effects also depend on the technique(s) for which it serves as a supplemental method for spoil disposal.

[c] Aggregating environmental parameters into a single index is difficult and often involves value judgments with respect to relative importance of the factors involved. These totals assume equal weighting of environmental impacts. Use of other weights could alter the ranking of the techniques.

[d] This ranking is for area mining in the eastern and central coal regions with adequate rainfall for vegetation. Area mining in the far west may well be unacceptable unless vegetation can be reestablished.

It is important to recognize now that this problem exists, and that ocean mining methods be developed so that pollution from these operations can be eliminated, or at least minimized.

Similarly, the need for energy sources may lead to use of the oil shale resources in the Rocky Mountain area. Nonpolluting mining techniques should be used to recover this resource.

5.3 Data Interpretation Aids and Prediction Methods Pertaining to Pollution Sources from Mining

5.3.1 Statement of purpose: Most of the available data pertaining to mining pollution consists of water analyses. The key to a good predictive model for mining sources lies in relating water quality data obtained from routine analysis to the source of contaminants which may be found in the sample. Concepts for such a model are presented here.

In general, water quality data are representative of the kinds of activities which are occurring in a particular watershed. Physical and chemical data reflect fundamental laws of physics and chemistry, and data must be explainable in terms of these laws. For the case of mine drainage, a check of anion-cation balance is very useful: positive ionic charge (cations) from hydronium and metallic ions must be equal to negative ionic charge (anions) from sulfate and bicarbonate ions. The utility of anion-cation balance is discussed in the 13th Edition of Standard Methods for the Examination of Water and Wastewater, pp. 38-39.2/ Variance from equality is significant, and means that other materials are in solution and have not been detected by the analysis. Nomograms using this relationship have been developed and are presented. Methods for translating raw data to a form where the anion-cation balance can be checked are also presented.

It is recognized that most planners and engineers have limited resources to obtain the information which is desired for coping with pollution problems. Therefore, it is essential that resources be used in the best possible manner to yield as much information as possible. This evaluation of mining pollution represents an initial effort to give planners and engineers tools with which more information can be gleaned from existing data and data gathered in the future.

5.3.2 Empirical aids for interpreting water quality data:

(a) Nomograms for mine drainage data interpretation: The chemistry of formation of mine drainage and of its reactions with materials in the watershed must yield an electrically neutral system in which positive charge (cations) is balanced with negative charge (anions). Two simple nomograms, Figures 5-1 and 5-2, have been developed which can be used to determine how close the balance is from analytical data obtained from water samples. The nomograms have been developed using several hundred data for mine drainage in Appalachia.[28] However, the principles on which they are based are universal, and the nomograms are applicable to any mine drainage containing sulfate and acidity plus associated neutralization products (hardness). The choice of nomogram depends upon the pH of a particular sample and the method of hardness determination.

Both nomograms assume that the principal source of negative charge is sulfate anion, and the principal sources of positive charges are hardness and hydronium (acid) cations. The two nomograms are based upon the rule of thumb that sulfate is equal to net acidity plus hardness. Net acidity is the difference between measured acidity and measured alkalinity (see Section 5.3.3). Hardness generally consists of calcium and magnesium cations. In the case of mine drainage, iron, manganese, and aluminum can also contribute to hardness.[2] The general equation is thus:

Sulfate (in milligrams per liter $CaCO_3$) = Net acidity (in milligrams per liter $CaCO_3$) + Hardness (in milligrams per liter $CaCO_3$)

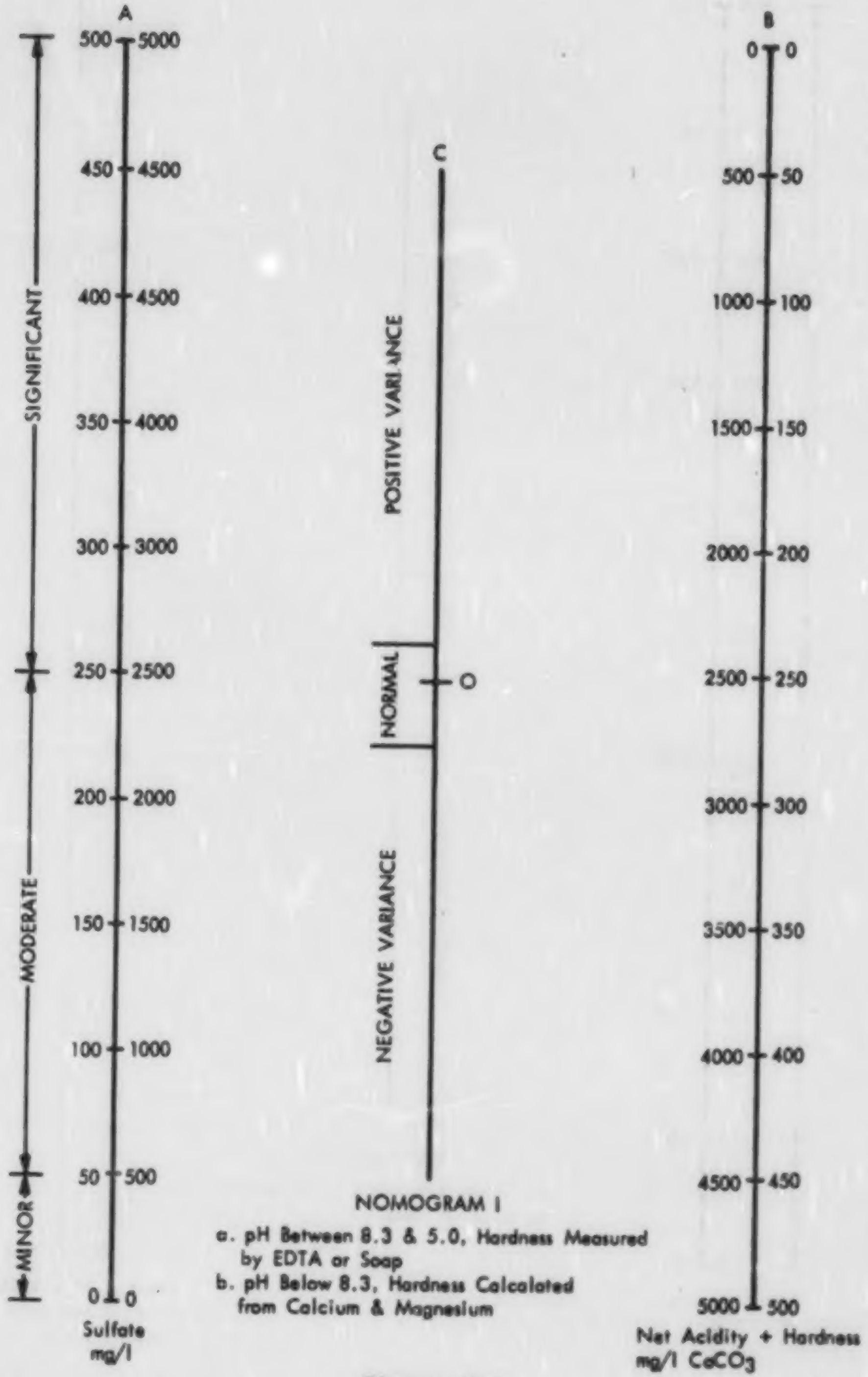
The conversion of milligrams per liter of sulfate as SO_4 to milligrams per liter of sulfate as $CaCO_3$ has been built into the nomograms. Thus, the usual sulfate reporting units (milligrams per liter as SO_4) can be compared directly with the usual hardness and net acidity units (milligrams per liter as $CaCO_3$).

The two nomograms have been developed to accommodate differing pH's and differing ways that hardness is determined, and are used for the following cases:

Nomogram I (Figure 5-1):

a. Sample pH between 8.3 and 5.0; hardness measured by EDTA titration or soap precipitation.

b. Sample pH below 8.3; hardness calculated from calcium and magnesium concentrations.


A
500 5000
450 4500
400 4500
350 4000
300 3000
250 2500
200 2000
150 1500
100 1000
50 500
0 0
SIGNIFICANT
MODERATE
MINOR
Sulfate
mg/l
C
POSITIVE VARIANCE
NORMAL
O
NEGATIVE VARIANCE
B
0 0
500 50
1000 100
1500 150
2000 200
2500 250
3000 300
3500 350
4000 400
4500 450
5000 500
Net Acidity + Hardness
mg/l CaCO3

NOMOGRAM I

a. pH Between 8.3 & 5.0, Hardness Measured by EDTA or Soap

b. pH Below 8.3, Hardness Calcolated from Calcium & Magnesium

Figure 5-1

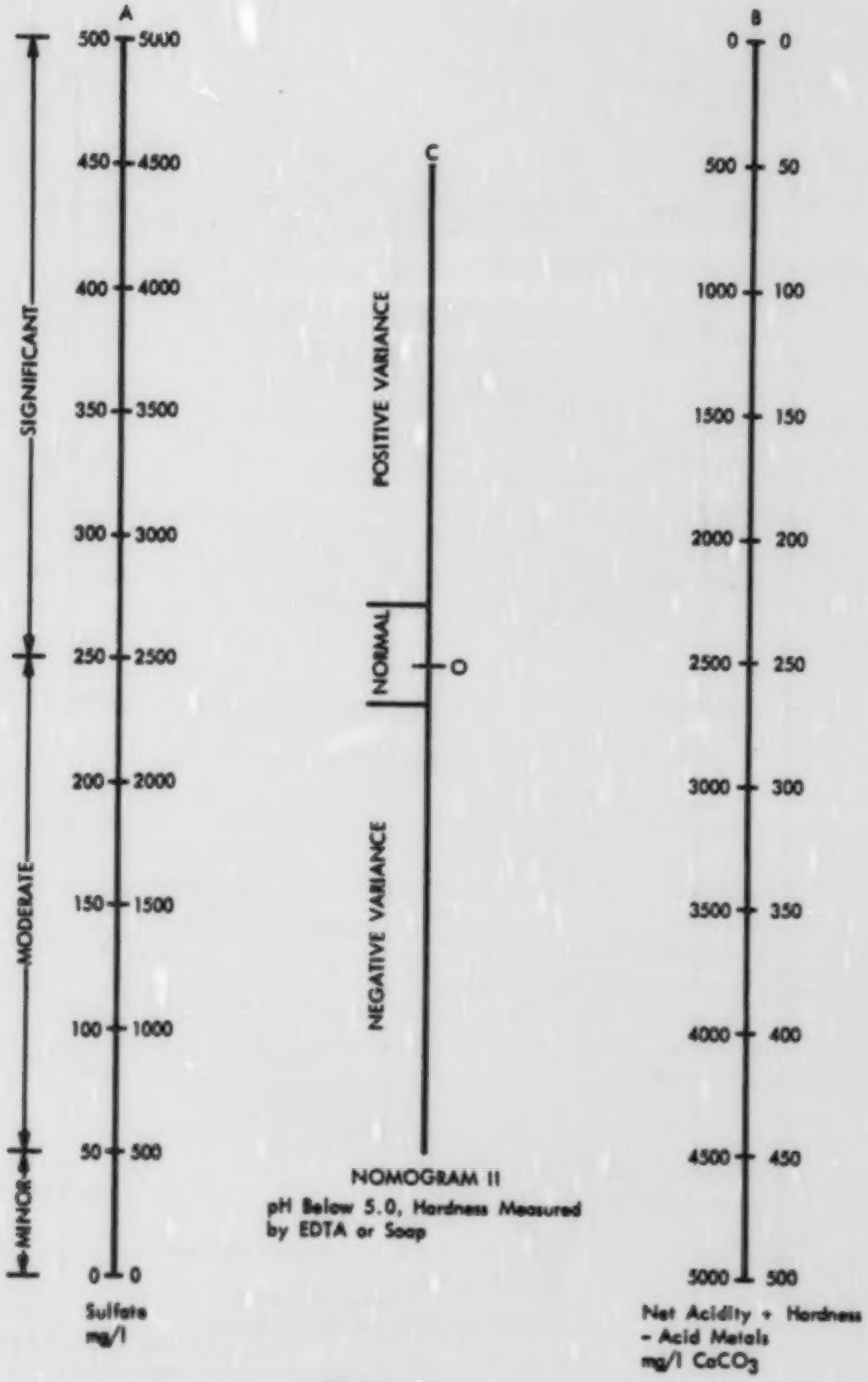

A
500 5000
450 4500
400 4000
350 3500
300 3000
250 2500
200 2000
150 1500
100 1000
50 500
0 0
SIGNIFICANT
MODERATE
MINOR
Sulfate
mg/l
C
POSITIVE VARIANCE
NORMAL
O
NEGATIVE VARIANCE
NOMOGRAM II
pH Below 5.0, Hardness Measured
by EDTA or Soap
B
0 0
500 50
1000 100
1500 150
2000 200
2500 250
3000 300
3500 350
4000 400
4500 450
5000 500
Net Acidity + Hardness
- Acid Metals
mg/l CaCO3

Figure 5-2

Nomogram II (Figure 5-2):

Sample pH below 5.0; hardness determined by EDTA titration or soap precipitation.

Selection of the proper nomogram is determined by sample pH and by the procedures used to determine hardness. The pH range of Nomogram I is limited to 5.0 to 8.3, since acidic cations (iron, manganese, and aluminum) are usually not present in large quantities in this pH range. At lower pH's, these metals are usually present in substantial quantities and report as hardness, causing an overestimation of cations. Discussion of how overestimation can arise is presented in Section 5.3.3. In Nomogram II, the acid metals (converted to calcium carbonate values) are subtracted from the sum of acidity and hardness.

The two nomograms each consist of three vertical lines. The left line (Line A) represents sulfate values reported in milligrams per liter SO_4. Two sets of indices are shown on Line A, one ranging from 0 to 500 mg/liter, and the other ranging from 0 to 5,000 mg/liter. The 0 to 500 mg/liter index (outside of Line A) has been arbitrarily divided into three categories: 0 to 50 mg/liter, representing a "minor" contribution of mine drainage; 50 to 250 mg/liter, representing a "moderate" mine drainage problem; and 250 to 500 mg/liter representing "significant" mine drainage. The 0 to 5,000 mg/liter index on the inside of the sulfate line is indicative of serious mine drainage problems.

The right line (Line B) on each nomogram represents the "cations" present in the sample as reported in milligrams per liter $CaCO_3$. As stated earlier, the value for Line B is the sum of net acidity plus hardness for Nomogram I, and net acidity plus hardness minus acid metals (iron, manganese, and aluminum) for Nomogram II. Line B also has two sets of indices to permit nomogram utilization over a range of concentrations. The outside index ranges from 0 to 500 mg/liter $CaCO_3$, and the inside ranges from 0 to 5,000 mg/liter.

Line C is used as a measure of how well sulfate anion balances with acid-hardness cations. A tie line connecting a sulfate value on Line A with an acidity-hardness value on Line B will intersect Line C at the zero point, if ionic charge balance is present in the data. The zero point on Line C is the solution to the equation:

$$\text{Sulfate} - (\text{Net Acidity} + \text{Hardness}) = 0$$

Line C is divided into three ranges. The NORMAL range represents reasonable chemical balance between sulfate and acidity-hardness. If the amount of sulfate is significantly greater than the amount of acidity-hardness, then a POSITIVE VARIANCE is indicated. If sulfate is less than acidity-hardness, then the nomogram will indicate NEGATIVE VARIANCE.

When comparing sulfate with acidity-hardness, the outside sulfate index on Line A is measured against the outisde acid-hardness index on Line B, and vice versa. If an outside index is measured against an inside index, then erroneous intersections with the Line C will result.

The use of the nomogram involves the following steps:

1. The proper point on Line A is located by using the sulfate concentration found in the sample.

2. The proper point on Line B is located by determining the sum of net acidity (acidity less alkalinity) and hardness. This sum is used directly for Nomogram I; it is corrected for acid metals (reported as $CaCO_3$) in Nomogram II. To obtain the acid equivalents in milligrams per liter $CaCO_3$ for the acid metals, the following conversion factors are used.

Metal	Conversion Factor
Aluminum	Milligrams per liter $CaCO_3$ = 5.56 mg/liter Al
Iron	Milligrams per liter $CaCO_3$ = 1.79 mg/liter Fe
Manganese	Milligrams per liter $CaCO_3$ = 1.82 mg/liter Mn

3. After the appropriate points on Lines A and B have been chosen, a tie line is drawn between them. The intersection of the tie line with the Line C shows how closely the anions in the system balance with the cations. If a balance is achieved, then the intersection is above the normal range, a POSITIVE VARIANCE is noted indicating an excess of negative charge or a deficiency of positive charge. If the intersection is below normal, NEGATIVE VARIANCE exists, which signifies excess positive charge or deficient negative charge. If either positive or negative variance is found, the analytical information is incomplete with respect to cations of anions, or both.

The following discussion is presented to show what positive and negative variances signify.

Positive Variance

1. Cation deficiency or sulfate excess.

2. Alkali metals (sodium and potassium) may be present.

3. If drainage has passed through feldspar or mica-containing soils or strata, presence of potassium is likely.

4. Mine drainage has been neutralized by sodium alkalinity, i.e., soda ash or sodium bicarbonate.

5. The sample contains sodium sulfate from an industrial waste discharge.

6. If Nomogram I is used and hardness is determined by atomic absorption values for calcium and magnesium, other metals contributing to hardness, e.g., zinc, may be present.

7. If Nomogram II is used, the contribution to the acidity by iron, manganese, and zinc may be overestimated; the correction factor for acid metals may thus be too high, resulting in a cation deficiency.

Negative Variance

1. Sulfate deficiency or cation excess.

2. Chloride or nitrate may be present, arising from industrial discharges of calcium chloride or nitrate.

3. If the sample is taken in winter, calcium chloride may be due to use of deicing salt on roadways.

4. If ferrous iron or manganese is present in the sample, they can be partially oxidized resulting in abnormally high acidity values.

5. If Nomogram I is used and hardness measured by EDTA titration or soap precipitation, small amounts of ferric iron and aluminum would contribute to hardness as well as acidity, resulting in a cation excess.

The fact that an intersection between sulfate and acidity-hardness falls in the NORMAL range does not necessarily indicate that the analysis is complete; it merely means that the contribution of mine drainage has been accounted for. For example, if the water sample contains sodium chloride, the nomogram would not so indicate. Thus, the nomograms must be used with judgment, realizing that they do not necessarily yield a total description of samples.

Since either positive or negative variance indicates incomplete or inaccurate analytical data, the nomograms can provide information pertaining to what data are missing, and can be used to indicate where the missing data may be found; i.e., does one look for chloride or potassium? Whether the analyst would look further for the missing data is a matter of judgment and policy.

(b) Aids for converting raw data into useful form: Raw analytical data are normally reported as a concentration of a particular substance in parts per million (ppm) or milligrams per liter (mg/liter). Since a liter of water weighs 1,000 g or 1 million milligram, parts per million and milligrams per liter are equivalent.

$$\text{ppm} = \text{mg/liter}$$

If data are to be used to check the anion-cation balance then concentration data in milligrams per liter must be converted into milliequivalents per liter (meq/liter).

Milliequivalents per liter are often arbitrarily expressed as milligrams of $CaCO_3$ per liter (mg/liter $CaCO_3$). The term milligrams per liter $CaCO_3$ is convenient since most analyses for the general parameter of "hardness" are reported as such. Alkalinity and acidity, also related to hardness, are generally reported as milligrams per liter $CaCO_3$. The use of calcium carbonate equivalents is also convenient because the equivalent weight of $CaCO_3$ is 50 mg/meq.

$$\text{mg/liter } CaCO_3 = 50 \times \text{meq/liter}$$

A table showing conversion factors for common cations and anions to either milliequivalents per liter or milligrams per liter $CaCO_3$ is presented in Table 5-9. This table can be used to convert concentration to the form of either milliequivalents per liter or milligrams per liter $CaCO_3$. By adding up the milliequivalents per liter of cations and comparing to the similar sum of anions, it is possible to assess the completeness of analytical data, and to judge which data may

TABLE 5-9

FACTORS FOR CONVERTING CONCENTRATION DATA INTO FORMS FOR CHECKING ANION-CATION BALANCE

Cation	meq/liter = mg/liter times:	mg/liter as $CaCO_3$ = mg/liter times:
Aluminum, Al^{+++}	0.111	5.56
Ammonium, NH_4^+	0.0554	2.77
Barium, Ba^{++}	0.0146	0.729
Calcium, Ca^{++}	0.0499	2.50
Copper, Cu^{++}	0.0315	1.58
Iron:		
Ferrous, Fe^{++}	0.0358	1.79
Ferric, Fe^{+++}	0.0537	2.69
Hydrogen, H^+	0.992	49.6
Lead, Pb^{++}	0.00965	0.483
Potassium, K^+	0.0256	1.28
Lithium, Li^+	0.144	7.21
Magnesium, Mg^{++}	0.0823	4.12
Manganous, Mn^{++}	0.0364	1.82
Sodium, Na^+	0.0435	2.18
Strontium, Sr^{++}	0.0228	1.14
Zinc, Zn^{++}	0.0306	1.53

Anion	meq/liter = mg/liter times:	mg/liter as $CaCO_3$ = mg/liter times:
Borate BO_2^-	0.0234	1.17
Bromide, Br^-	0.0125	0.626
Chloride, Cl^-	0.0282	1.41
Carbonate, $CO_3^=$	0.0333	1.67
Bicarbonate, HCO_3^-	0.0164	0.820
Fluoride, F^-	0.0526	2.63
Hydroxide, OH^-	0.0588	2.94
Iodide, I^-	0.00788	0.394
Nitrate, NO_3^-	0.0161	0.807
Nitrite, NO_2^-	0.0217	1.09
Phosphate, $PO_4^{\equiv}$	0.0316	1.58
Monohydrogen Phosphate, $HPO_4^=$	0.0208	1.04
Dihydrogen Phosphate, $H_2PO_4^-$	0.0103	0.516
Sulfate, $SO_4^=$	0.0208	1.04
Sulfide, $S^=$	0.0624	3.12
Bisulfide, HS^-	0.0302	1.51

be missing if equality is not achieved. The nomograms described earlier have been developed using this concept.

Other aids to water quality data interpretation using this concept are discussed in Hem's treatise entitled Study and Interpretation of the Chemical Characteristics of Natural Waters.[33] This treatise details several simple graphical methods which pictorially represent water quality. Use of these methods require more complete analyses than are generally available for describing pollution from mining operations. It is likely that these methods may be useful in the future when more complete sets of data are available.

The Hem models are applicable to pollution sources involving salinity. The unknown extent of salt pollution from gas and oil well drainage should be readily ascertained using these models. The models have been useful in tracing salt water intrusion into fresh water supplies in coastal areas.

Hem's descriptions of the several models are good sources of information about possible ways and means of presenting analytical data in a simple and useful form. A careful study of the document may assist the planner or engineer in developing ways to manipulate data into a more readily understandable or useful form.

The U.S. Geological Survey has published a report entitled The National Hydrologic Bench-Mark Network.[9] This report describes stations designated to provide data on stream basins which have not been seriously affected by man's activities, and reports data in a straightforward manner. Thus, data obtained from these stream basins are not influenced to a great degree by the environmental alterations caused by population growth and changing land use patterns.

There are 57 bench-mark basins in 37 states. These basins are in areas having a wide variety of climate and topography. Data acquired from these stations can be used to estimate background concentrations of specific indicators of pollution. By comparing data obtained on a stream known to be affected by man with data acquired from a bench-mark stream having similar characteristics of climate, geology, and topography, it should be possible to gain insight on the nature and extent of pollution in the watershed under consideration.

(c) Trends observed from mine drainage data: Data concerning stream quality in Appalachia are abundant.[5,28,44] These data have been plotted against one another to determine trends which exist that could be the basis for additional tools for data interpretation. The plots are summarized below.

Plot	(A) Number of Plots Correlating	(B) Number of Plots Not Correlating	Net Correlatability (A)-(B)
Metals and Dissolved Solids vs Stream Flow	6	5	+1
Number of Sources vs Acid	12	9	+3
Drainage Area vs Acid	0	8	-8
Sulfate vs Acid	10	3	+7
Stream Mile vs Acid	1	3	-2

This simple approach shows that certain variables are correlatable and thus potentially translatable into prediction tools. The greatest number of correlations was found with sulfate and acid, the system on which the nomograms described earlier are based.

The next greatest number of correlations is found in the plots of number of drainage sources versus acid in the stream. This correlation is worth developing further. Factors which affect this correlation are: tonnage of product mined (past and present), geographical location, soil type, geology, topography, and climate.

Plots which were noncorrelating include drainage area versus acid, and stream mile versus acid. These plots indicate that the size of the drainage area is not as important as the number of sources in the area, and that pollution from mining is more likely to arise from springs, abandoned mine shafts, leaching gob piles, etc., than from the general region in which mining occurs.

Definitive relationships for metals and dissolved solids versus stream flow were not uncovered.

The relationships of stream data to mining sources and to geologic and hydrologic conditions that may result in pollution are real. The trends discussed here are capable of being reduced to simple prediction tools, in a logical next step in the continuing effort to describe more fully and completely the nature and extent of pollution from mining operations.

5.3.3 Discussion of sampling and analytical methods: This section discusses sampling procedures and analtyical methods for mining-related wastewaters.

(a) Sampling techniques and procedures: The acquisition of a truly representative sample is of great importance, if the data obtained from the sample are to be of use to the planner or engineer. Hem's treatise on the Study and Interpretation of the Chemical Characteristics of Natural Water[33/] presents in great detail the problems associated with obtaining a representative sample. The heart of the problem lies in the fact that a body of water is not homogeneous, particularly if the water is moving. For example, Hem presents analyses of the Susquehanna River water taken at Harrisburg, Pennsylvania, in which east bank samples are acid (pH = 5.2) and west bank samples are alkaline (pH = 7.4). Concentrations of hardness and sulfate also vary widely. Thus, the question is raised: What does an average analysis of Susquehanna River water at Harrisburg really mean? Knowledge of the nature and extent of sources contributing to the analytical data is necessary to answer the question.

Water quality data can be no better than the quality of the sample from which the data are obtained. In recent years, automatic samplers and analyzers have been installed as a means of gathering a large number of data per man-hour of effort. However, the automatic devices have the shortcoming of not being able to judge whether a sample is good or bad. As a result, some data obtained by automatic methods may be subject to question. For example, if a sample is taken, and some sediment passes through the filtering device into the analyzer, the data reported by the analyzer will not truly reflect the composition of the aqueous plane.

Another important aspect of sampling and analysis is the time lag between sample acquisition and sample analysis. This time lag is of considerable importance in mine drainage samples because reactions will continue after the sample has been taken. For example, if the water sample contains iron sulfate, the ratio of ferrous to ferric iron, an important indicator of mine drainage, will change. If the sample contains aluminum ion, sample aging may permit hydrolysis of aluminum into aluminum hydroxide, and suspended solids (sediment) would then be overestimated and aluminum underestimated.

Time lag is of concern when automatic samplers are used without automatic analyzers. An automatic sampler collects a series of samples and holds them until they are retrieved for analysis. The frequency of sample retrieval can vary from several hours to several weeks. Thus, the samples taken at the beginning of the cycle have aged longer than those taken at the end. Analytical data obtained from the samples can reflect the aging process, and should be interpreted with sample age in mind.

The U.S. Geological Survey, Office of Water Data Coordination, has recently published a preliminary report concerning Recommended Methods for Water-Data Acquisition.64/ This report contains valuable information pertaining to all aspects of sampling and analysis, including procedures for acquiring, preserving, and analyzing samples. Techniques are described in detail relating to the following subjects:

Surface water

Groundwater

Fluvial sediment

Biologic, bacteriologic, and chemical (organic) quality of water

Chemical (inorganic) and physical quality of water

Automatic water quality monitors.

The information in this handbook is of great assistance to planners and engineers who deal with water quality problems.

(b) Analyses usually performed: Analyses for mine drainage usually consist of all or some of the following: acidity, alkalinity, sulfate, hardness, iron, manganese, and aluminum. Cations are reported as acidity, hardness, iron, manganese, and aluminum; anions as sulfate and alkalinity. In general, all metal cations will report as hardness except the alkali metals, i.e., sodium, potassium, and ammonium. Anions which may be found in significant amounts in surface waters include chloride and nitrate.

Metallic cations: Cations can be measured by several methods. One method is atomic absorption spectroscopy, which yields precise information for specific metals sought. This method involves sophisticated instrumentation usually not available to field water quality laboratories. The atomic absorption method is most useful for determining traces of metals present in the sample.

For common metal ions in water samples, wet chemical techniques can be employed. Those techniques can be used to determine most metals with exception of the alkalis, sodium and potassium. Wet chemical techniques used to measure "total hardness" will give results which include the common heavy metals as well as calcium and magnesium, the usual components of hardness.[2] The two common techniques for determining total hardness are (1) titrating the sample with EDTA (ethylenediamine tetraacetic acid) and (2) precipitation of metal stearates with soap. If calcium and magnesium need to be reported separately, then any heavy metal contribution to the total hardness must be subtracted.

Individual concentrations of metallic cations (excluding alkaline earth and alkali metals) can often be estimated using colorimetric methods. Standard methods are available for laboratory analysis,[2,3,22] as well as field kits for on-site analysis. These field kits are available from several suppliers. Use of these methods will yield information pertaining to heavy metals which may be present in the sample.

Acidity: Acidity measurements are conducted by titrating the sample with standard sodium hydroxide to a prechosen pH value. The final pH of most acidity determinations is 8.3, the point where phenolphthalein indicator changes color. However, in recent years, the pH of 7.0 has been suggested as an end point, since it represents exact theoretical neutralization in aqueous systems. Since most data have been obtained by titrating to pH of 8.3, they may reflect an overestimation of acidity.

Acidity can also be more accurately determined if metals which are potentially oxidizable in the titration with standard base are taken into consideration. The most common ones found in mine drainage are ferrous iron and manganese. The reactions are:

$$2Fe^{++} + 4OH^{-} + 1/2\ O_2 + H_2O \longrightarrow \underline{2Fe(OH)}_3$$

$$Mn^{++} + 2OH^{-} + 1/2\ O_2 \longrightarrow MnO_2 + H_2O$$

These two reactions will consume base and hence report as acid, even though the consumption of base arises from neutral salts, e.g., ferrous or manganous sulfates. Thus, if ferrous iron or manganese is present in the sample, one should be aware of the possibility that the measured acidity may be high.

One method of ensuring that acidity measurements do include acid potentially present from ferrous iron and manganese is to oxidize the sample with hydrogen peroxide prior to the acidity determination.[46] This oxidation will convert all ferrous iron into ferric iron, and the manganese into manganese dioxide.

$$Fe^{++} + 1/2\ H_2O_2 + 2H_2O \longrightarrow \underline{Fe(OH)}_3 + 2H^+$$

$$Mn^{++} + H_2O_2 \longrightarrow \underline{MnO_2} + 2H^+$$

By measuring the ferrous iron and manganese contents in the original sample, it is possible to correct the acidity for that generated in hydrogen peroxide treatment of ferrous iron and manganese.

This procedure should yield more accurate acidity measurements, since air oxidation of the iron and manganese can vary widely depending upon the nature of the sample and the analyst's technique.

Ferric iron or aluminum in solution will also consume hydroxide. Since these cations are in their highest oxidative state, they will report as acid without the need for hydrogen peroxide treatment.

$$Fe^{+++} + 3OH^- \longrightarrow \underline{Fe(OH)}_3$$

$$Al^{+++} + 3OH^- \longrightarrow \underline{Al(OH)}_3$$

Sulfate: Analysis for anions includes sulfate and alkalinity determinations. Sulfate analyses are generally simple and reliable. The techniques include the precipitation and weighing of barium sulfate, light scattering by finely divided barium sulfate, and titrating with barium chloride using thorin indicator. The EPA method,[22] which involves titration with barium chloranilate, is not generally satisfactory for mine drainage since cations (calcium, aluminum, and iron) present in the sample will interfere with the sulfate determination unless special pretreatment measures are taken.

Alkalinity: Alkalinity is determined by titrating the sample with standard acid to pH of 4.5. Mine drainage samples having pH's greater than 4.5 may thus contain alkalinity as well as acidity. Traditionally, alkalinity has been associated with the bicarbonate-carbonic acid, and carbonate-bicarbonate equilibria in waters.

At pH's above 8.3, water contains carbonate and bicarbonate in equilibrium; below pH of 8.3, waters contain bicarbonate and carbonic acid in equilibrium. Since the pH of mine drainage is usually less than 8.3, one is concerned with the bicarbonate-carbonic acid equilibrium.

Bicarbonate arises in mine drainage through the dissolution of limestone by acid. If the drainage passes through a limestone-abundant formation (as it usually does for those drainage samples having a pH above 4.5), then bicarbonate will be present and contribute anions to the system.

Net acidity: The preceding discussion dealt with alkalinity and acidity, and how analyses can result in inconsistencies and misinterpretation. A convenient way around the complexities of the chemistry involved in interpreting acid and alkalinity data are through the use of "net acidity." Net acidity is the difference between measured acidity and measured alkalinity. Net acidity can be either positive or negative. If it is positive, then acid (or acid forming salts) are present in the system. If it is negative, the bicarbonate can be considered a genuine species in the system.

(c) Analyses not usually performed: It is impractical in routine analyses to determine every element which could be present in a given sample. However, analysis for anionic species, particularly chloride and nitrate, would help to complete the picture of a given sample. Standard field kits are available for determining chloride and nitrate.

Chloride and nitrate: Chloride and nitrate are generally present in most natural waters. Therefore, they will normally be present in mine drainage, though to a smaller extent than sulfate. The cation component of the chloride and nitrate salts is usually alkali or alkaline earth metal. If it is alkaline earth, then it will be reported as hardness.

If substantial quantities of chloride or nitrate are found in waters known to be contaminated with mine drainage, then one must suspect that they are arising from sources other than mining. Sources may be industrial discharges of lime-treated hydrochloric or nitric acids. These discharges would add calcium chloride or calcium nitrate to the water. In wintertime, calcium chloride deicer can be flushed into the watercourse. Other sources would also include salt springs, perhaps from abandoned oil/gas wells in the areas, which would add chloride. Runoff from agricultural land can be a source of nitrate.

Alkali metals: Missing cations, on the other hand, are probably mainly sodium and potassium. If these ions are present in quantities greater than that expected in the background, they can be considered to be pollutants. A likely source of sodium is from oil/gas wells which may drain into the watershed.

Potassium, on the other hand, can arise as a consequence of mine drainage. As has been pointed out in Section 5.2.2, alkali oxide contents of clays will neutralize acid and dissolve aluminum. If feldspathic and illitic (mica-containing) clays are in the watershed, mine drainage can be expected to contain potassium.

This source of potassium will be present even if the aluminum concentration in the sample is low. Aluminum solubilized from clays and neutralized by limestone can be removed. Once potassium has been dissolved, it will stay in solution. Thus, knowledge of geology, both rock composition and soil horizons, can be used to predict whether potassium is a reasonable constituent of surface or groundwaters.

Alkali metals are easily determined by flame photometry or atomic absorption spectroscopy. However, these tools are not always available in field or small local laboratories. Their presence can often be deduced from knowledge of other chemical analyses, including knowledge of the geology of the area being studied.

Heavy metals: Heavy metals may also be missed, particularly if atomic absorption is used as the single tool for heavy metal determinations. In preceding discussion, it has been shown that most heavy metals will report as hardness if determinations are made using EDTA titration or soap precipitation.

In hard rock mining areas where metal ores are mined, one should be especially concerned with the possibility of heavy metals. As discussed in Section 5.2.4, drainage from hard rock mining areas consistently contains copper,zinc, arsenic, and lead in addition to the usual iron, manganese and aluminum.

5.3.4 *Models for predicting pollution quantities*: Several studies have undertaken to develop models which would predict pollution. This section contains brief descriptions of the important models for predicting mine drainage and sediment.

(a) *Models for predicting mine drainage*: Various models have been developed which can be used as predictive tools for mine drainage and leachate from refuse and spoil piles. The most complete model has been developed around pyritic oxidation and should be applicable to both coal and hard rock mining areas containing associated waste pyritic materials.

The Ohio State University Research Foundation, with EPA support, has developed a model for predicting pyrite oxidation from coal mines. Their report, entitled *Pyritic Systems: A Mathematical Model*, discusses in detail the pyrite oxidation mechanisms.[41] Data obtained from an experimental mine in Ohio were used to develop a computer program which would predict the flow and chemical characteristics of the mine drainage. The program was tested on auger holes at a site other than the experimental mine (but within the same coal seam). Actual drainage data from the auger holes correlated very well with that predicted by the computer program.

The program was developed using very general principles associated with the oxidation of any pyritic system. These principles should apply to both coal and hard rock mining. Factors affecting the volume and composition of mine drainage include water tables, seasonal variation, rainfall amounts, local hydrology, etc. Thus, the computer program should be able to predict the quantity and quality of mine drainage, particularly that associated with active and abandoned mining operations in Ohio.

The applicability of the simulation program will be less precise for Appalachian coal mining areas outside of Ohio, and even less so for the hard rock mining areas of the West. Nevertheless, the simulation offers a means of evaluating, in a preliminary sense, the pollution potential of pyritic systems in various regions.

While the pyritic systems model involves computers and a lengthy computer program, the model is a valuable information tool for persons dealing with mine drainage.

(b) Limestone requirements for pyritic spoils and overburden: A very useful tool for predicting pollution potential from mining activities has been developed at the University of West Virginia.[70] This study involves the prediction of acid mine drainage from spoil banks and coal overburden materials based upon sulfur content of materials. Detailed descriptions of how sulfur content (acid forming potential) of spoil and overburden materials is translated into limestone requirements for controlling acid formation[29] were presented at the First Symposium on Mined-Land Reclamation, Pittsburgh, Pennsylvania, March 7 and 8, 1973. Reprints of the symposium procedings are available from Bituminous Coal Research, Inc., 350 Hochberg Road, Monroeville, Pennsulvania 15146.

The equation for acid generation from West Virginia spoil is:[29]

Acid generated in milliequivalents acid/100 g sample = 4.93 + 52.29 X (percent pyritic and organic sulfur in spoil); $R^2 = 0.970$

The samples must be pretreated to remove sulfate and carbonate prior to determining pyritic and organic sulfur. Spoil samples vary from overburden and undisturbed rock samples in that some acid-producing sulfur in spoil has been oxidized to sulfate. Hence sulfate must be removed in order to predict potential acidity.

Equations for predicting acid forming potential in West Virginia rocks and overburden have been established[70] as a function of rock type. This potential exists in nonmined areas, and can be used as a means of estimating acid formation when and if mining operations commence. The equations are:

Rock Type	Equation Acid potential (milliequivalents of acid/100 g sample) =	
Sandstone	$-0.641 + 37.6(\%S)$	$R^2 = 0.728$
Shale	$-4.40 + 43.6(\%S)$	$R^2 = 0.864$
Sandstone and Shale	$-2.54 + 42.4(\%S)$	$R^2 = 0.862$

Sulfur determinations on the rock samples are made directly, since sulfate concentrations are generally low. Carbonate contents are also determined. The negative intercepts of the equations indicate that the rock does contain small amounts of neutralizing capacity.

While these equations specifically relate to West Virginia, the principles from which they are developed are universal. Any area which has a potential acid problem from coal refuse, sulfur-containing spoil banks, or unmined resources associated with oxidizable sulfur, can follow the methodology and procedures outlined in the West Virginia University studies. The procedures will yield equations similar to those described above for a particular region, and help to provide conditions for at-source control rather than control after mining operations have begun or have been abandoned.

(c) Infiltration of water into spoil banks: The infiltration of water in spoil banks has been modeled less successfully, by Vimmerstedt.[65] This study involved the use of lysimeters to determine important parameters in predicting mine drainage. Data generated from the lysimeters were compared with the empirical equation for infiltration:

$$V_o = 1/2\ St^{-1/2} + A$$

where V_o = infiltration rate (dimensions: length x time^{-1})

S = sorptivity (dimensions: length x time$^{-1/2}$)

t = time

A = permeability at zero capillary potential, and decreases with decreasing moisture content (dimensions: length x time^{-1})

Variations in infiltration rates could not always be accounted for by the variables: volumetric soil moisture, bulk density, and soil types. It was found that when the exponent for time (t) was changed from -1/2 to -1, the fit was improved. This observation may indicate that depth of water penetration into the spoil bank is a more important parameter than is sorptivity.

(d) Leachate quantities from spoil banks: The prediction of amounts of pollutant from spoil banks developed by Vimmerstedt and Struthers as a result of lysimeter studies has been more successful.[66] This study, based upon different spoil types in Ohio, has shown that the pollution generated from the spoil is dependent upon type of soil being leached. The classifications of spoil types are:

Toxic--pH of surface material less than 4.0 on more than 75% of the area.

Acid--pH from 4.0 to 6.9 over 50% of the surface area.

Marginal--50% to 75% of the surface area with a pH below 4.0, the remainder being acid, calcareous, or mixed.

Calcareous--pH above 7.0 or over 50% of the surface area.

The general findings of the study were that toxic spoil yielded the most acid and salts, in quantities nearly 100 times greater than did soil. Marginal spoils were the next worst polluters followed by calcareous and acid spoils. In addition, the lysimeter studies showed that the rate of pollutant leaching was quite rapid (half-life of 3 to 4 years) for toxic spoils, while the other spoils were leached at a slower rate (half-life of 6 to 8 years). The conclusion drawn was that spoil banks have a finite lifetime, and that they would become nonpolluting after an exposure of many years.

However, the lysimeter experiments did not provide for fresh surface exposure in the spoil during the course of the experiment. Therefore, the validity of this conclusion is somewhat questionable in the practical sense. Even with a half-life of 3 to 4 years, the amount of pollutant leached from toxic spoil was 50 times greater than that from soil.

In terms of pollutant quantities found in the first year, toxic spoil yielded about 94 metric tons/hectare (42 tons/acre) of acid and salts, marginal spoil about 22 metric tons/hectare (10 tons/acre), calcareous spoil about 4.5 metric tons/hectare (2 tons/acre), acid spoil about 3.4 metric tons/hectare (1.5 tons/acre), and soil about 1.3 metric tons/hectare (0.6 ton/acre).

(e) Pollution potential from spent oil shale: The Colorado State University has developed a prediction model for estimating water pollution potential of spent oil shale residues, under EPA auspices.[15] This report is of general interest to planners and engineers since it very carefully details the methodology which must be used in developing sophisticated models for predicting leachate and sediment. This methodology was used to develop a computer program. However, the logic and methodology for analyzing various parameters is useful in developing rule of thumb tools for predicting nature and extent of nonpoint pollution.

(f) Prediction of mine drainage volumes in localized areas: Models to predict mine drainage volumes on a county-wide basis have been described by Tybout.[51/] Equations have been developed relating the annual volumes of mine (underground) drainage to the mine ceiling area exposed by production over past years. Equations are presented for both active and underground mines:

Active underground mines:

Metric: $Y = 0.00223\,X_{(1-15)} + 0.00104\,X_{(16-34)}$

English: $Y = 0.0907\,X_{(1-15)} + 0.0424\,X_{(16-34)}$

$R^2 = 0.403$

Inactive underground mines:

Metric: $Y = 0.000504\,X_{(1-15)} + 0.00212\,X_{(16-34)}$

English: $Y = 0.0205\,X_{(1-15)} + 0.0865\,X_{(16-34)}$

$R^2 = 0.847$

where Y = thousands of liters (gallons) per year of drainage in the county (or other mining area).

$X_{(1-15)}$ = average annual square meters (square feet) of mine ceiling area exposed by production over the past 15 years in the county (or other mining area).

$X_{(16-34)}$ = average annual square meters (square feet) of mine ceiling area exposed by production over the 16th and 34th year in the past in the county (or other mining area).

Tybout admits that the equations are crude from a statistical concept. However, he believes that the equations are significant if used where large numbers of mines are available to reduce the relative size of the standard error.

Methodology for statistical analysis of existing data is outlined for different modes of mine drainage sources, i.e., active underground, abandoned underground, active surface, or abandoned surface. The basis of the analysis is the hypothesis that the rate of drainage (Y) from mines in a mining area is a linear function of coal production (X_j) in that area over all past years (j).

$$Y = \Sigma a_j X_j$$

The coefficients (a_j) of this equation are determined by regression analyses of drainage and production data extending as far back in time as possible.

(g) Models for predicting sediment: The second major nonpoint pollutant from mining operations is sediment. When land has been disturbed by mining, or when minerals extracted in the mining operation have been beneficiated, large quantities of waste residue can be generated. This residue can in some cases wash into streams causing siltation problems.

Models for predicting sediment loadings have been discussed in detail in Section 3.0 Agriculture, and Section 4.0 Silviculture. Sediment models specifically directed to mining operations are discussed here.

Models for sediment control have been developed from studies of surface mining operations in Appalachia. These models are good only for this region. In hard rock mining areas in the western United States, many sediment problems cannot be predicted accurately because of steep slopes, more abrupt elevation changes, a highly variable rainfall, and lack of soil in mining areas. Nevertheless, the models developed for Appalachia involve principles which can be used to develop models for the hard rock areas.

The U.S. Forest Service has developed a model to predict the outslope of spoil banks generated during coal mining operations in Appalachia.[40] The basic equation is:

Metric: $Y = 3.91X_1 + 0.529X_2 - 8.85$

English: $Y = 3.91X_1 + 1.734X_2 - 29.0$

where Y = slope distance covered below outcrop in meters (feet)

X_1 = highwall height in meters (feet)

X_2 = original slope in degrees

This equation can be used to determine the amount of disturbed area which can be tolerated in a particular locality by operating within depth of cut and highwall height limitations. These limits, established by regulatory agencies or voluntarily met by operators, can be used to protect property below the mining operation. Plots of the equation above and below the coal outcrop are presented as Figures 5-3 and 5-4. A typical cross-section of a contour mine using the plots is shown in Figure 5-5.

This equation does not take into account the potential of the downslope cover to slide.

(h) Rules of thumb for estimating sediment loads: Another study in Appalachia by the U.S. Forest Service[17] has shown that suspended sediment has increased to the 10,000 to 50,000 mg/liter range during strip mining operations, compared to a sediment level of only 150 mg/liter prior to mining. Sediment loads in nonmining areas ranged from 1,000 to 6,000 m^3/hectare of watershed, compared to 8,000 to 66,000 m^3/hectare of watershed in mined areas.

The ranges of these data indicate the wide variability of sediment problems within single small watersheds, and substantiate the difficulties associated with predicting sediment loadings from mining activities. Part of the variation is related to the degree of reclamation and the age of the reclaimed land.

Other rule of thumb estimates based upon experience with mining operations in Kentucky are: (1) that the erosion loss from spoil banks is 790 metric tons/hectare/year (350 tons/acre/year), and (2) the sediment yield in watercourses is 340 metric tons/hectare/year (150 tons/acre/year).[19]

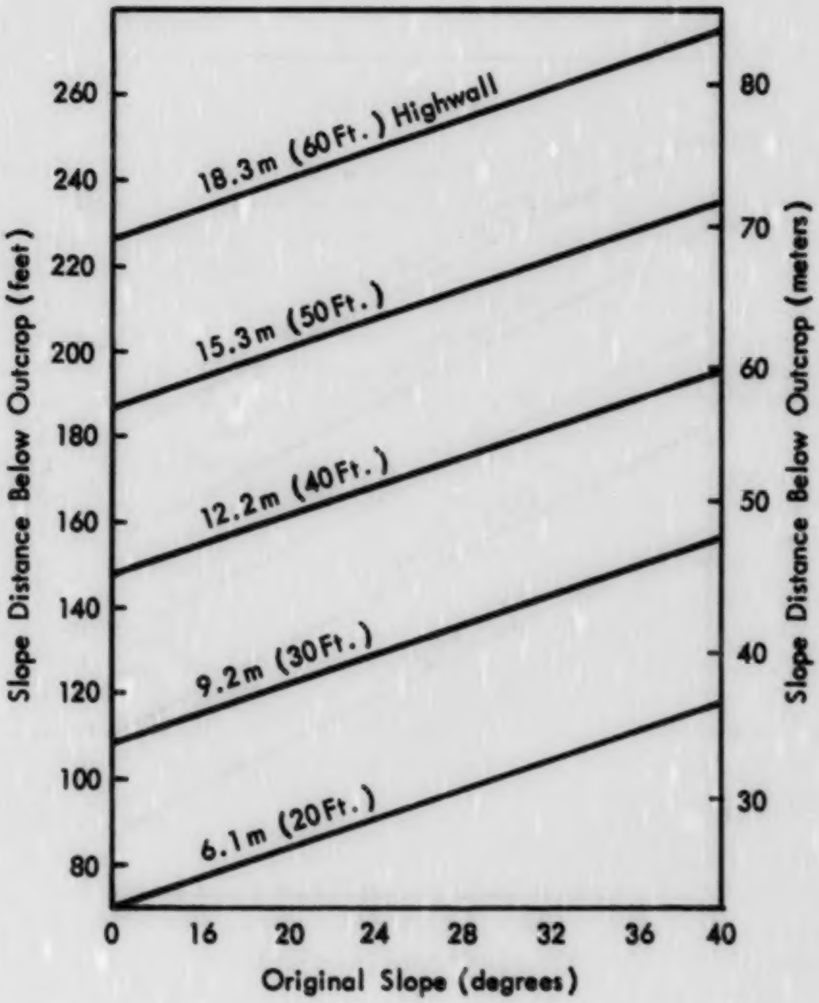


Figure 5-3 - Predicted Slope Distance Covered with Spoil Below Outcrop for Various Highwall Heights (Adapted, Ref. 40)

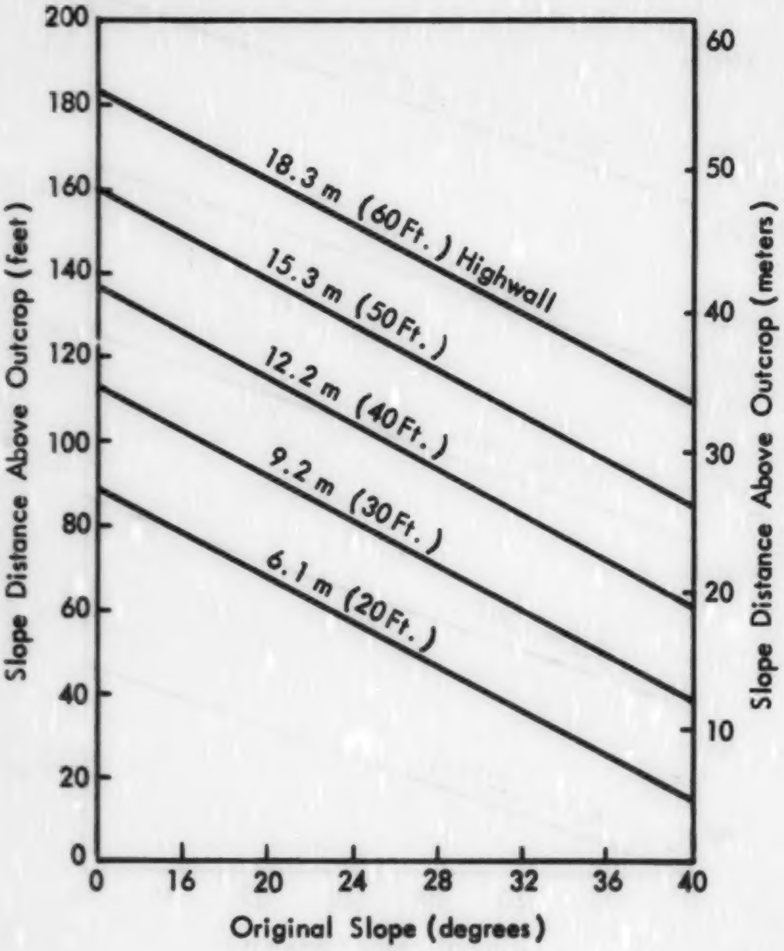


Figure 5-4 - Predicted Slope Distance Excavated Above Outcrop for Various Highwall Heights (Adapted, Ref. 40)

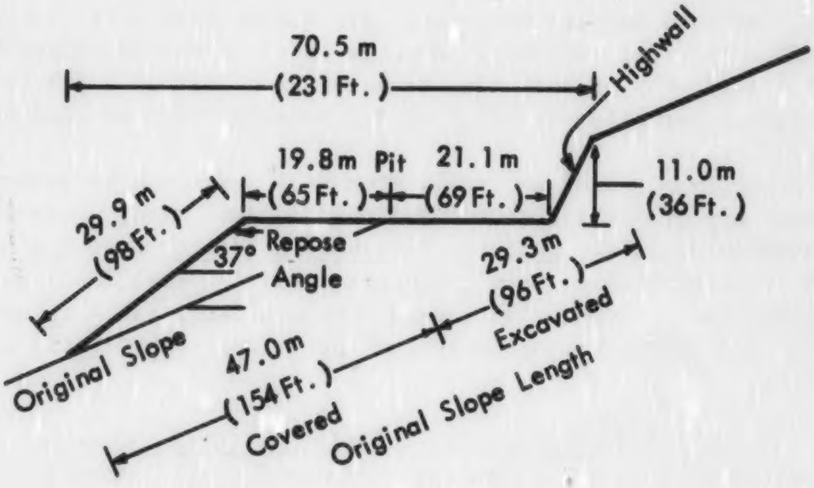

70.5 m
(231 Ft.)
Highwall
19.8 m
(65 Ft.)
Pit
21.1 m
(69 Ft.)
11.0 m
(36 Ft.)
29.9 m
(98 Ft.)
37°
Repose
Angle
29.3 m
(96 Ft.)
Excavated
Original Slope
47.0 m
(154 Ft.)
Covered
Original Slope Length

**Figure 5-5 - Typical Cross-Section of Contour Strip Mine (Dimensions are Means of 39 Observations)
(Adapted, Ref. 40)**

While these values do not appear to have been correlated with other parameters (slope, rainfall, and soil type), they do offer a crude approximation of what might be expected in the way of erosion and sedimentation in a watercourse.

(i) Sediment from haul roads: Roads used to carry mined products from the mining operation to processing operations also are potential sources of sediment problems. Weigle[68] has observed that the degree of erosion from abandoned coal bank roads in Kentucky depends on soil type. For sandy-silt soil, the erosion rate was 6.6 cm (2.6 in.) of road surface per year. For clayey-silt soil, the rate was 16.7 cm/year (5 in/year). Average width of the abandoned roads was 19.8 m (65 ft), translating to an erosion loss of 1,300 to 2,500 m^3 of sediment per kilometer (1.7 to 3.3 acre-ft/mile) of road annually.

Sediment yield from haul roads can be reduced if the roads are properly designed and constructed. Weigle has written a handbook entitled Designing Coal-Haul Roads for Good Drainage.[67] While this pamphlet is written primarily for coal roads in forested lands, the principles discussed should be applicable to any road associated with a mining operation, be it coal, hard rock, or other operations.

5.3.5 Methods for locating pollution sources: Improved methods of locating mined areas are needed if control procedures are to be initiated for specific problems. The problem may be more severe in the less densely populated western United States than in Appalachia. In the West, many old prospector pits, usually less than 1 acre of disturbed land, have been abandoned and left unfilled. Most of these pits have gone unreported unless mineral values worth exploiting were found.

In the coal mining regions of Appalachia, many communities depend upon mine-drainage-containing waters as sources for industrial and domestic water supply. Hence, drainage from these mines represents a serious source of concern to those localities affected. The fact that abandoned mines cannot be accurately pinpointed and mapped makes control-at-the-source procedures impossible to apply.

Several studies have been undertaken to determine locations of abandoned mines through remote sensing. One study, conducted for the Environmental Protection Agency by HRB-Singer, Inc., State College, Pennsylvania, involved the evaluation of several geophysical methods to locate abandoned underground mines.[34] Among the techniques used were: airborne infrared radiometry, electrical resistivity, magnetics, induced polarization, self-potential, very-low frequency electromagnetic refraction and reflection, and seismic refraction and reflection. Of these techniques, airborne infrared radiometry proved to be the most useful. Some correlations existed in the data, but when the techniques were applied to other areas, they failed to discover "known" abandoned mines. It was concluded that conventional geophysical methods were unable to locate abandoned mines. However, with improved sensitivity devices and a better understanding of the principles of geophysics, such techniques may be useful in the future.

Disturbed land has been "sensed" by earth satellites and aerial photography.[18] This technique is expensive and requires skilled persons to interpret photographic images. Satellite data are of relatively low resolution (about 80 m), and would fail to detect small prospector pits such as are found in the West. Aerial photography, on the other hand, has higher resolution and can locate most sources of disturbed land. This technique is particularly useful if color photography is used. However, aerial photography is an art, and useful information must be identified by highly trained persons. In addition, ultimate identifiers and descriptors of the area must be determined by ground reconnaissance.

Thus, the most important method of locating abandoned mines or land disturbed by mining activities, and establishing the nature and extent of pollution from these sources, is thorough exploration on the ground. The techniques used in a ground exploration are reported in several Environmental Protection Agency studies. A typical study has been conducted by the Halliburton Company, Duncan, Oklahoma,[30] dealing with a field investigation to locate and define unknown or hidden drift mine openings in the Browns Creek Watershed of the West Fork River in West Virginia. This report is a detailed account of the steps which must be undertaken to locate abandoned mining operations in a heavily mined area. The process is time consuming and expensive, but is necessary if pollutions from abandoned mining operations is to be controlled.

5.3.6 Information sources pertaining to pollution from mining: Sources of general water quality information, and sources of specific water quality information are presented below.

(a) Sources of general water quality information: The U.S. Geological Survey, Office of Water Data Coordination, has published the Catalog of Information on Water Data, a file of information about water data acquisition activities. Activities reported in this catalog are listed in three indexes: "Index to Water-Quality Section,"[59] "Index to Surface-Water Section,"[58] and "Index to Groundwater Stations."[57] These indexes describe water data acquisition activities at specific points in the country, and include the following information: who is reporting, what is reported, what is the scope of the activities, and what are the periods of record.

Entries in the indexes are related to three sets of maps, one set for each of the three indexes: Water Quality Stations,[62] Surface Water Stations,[61] and Groundwater Stations.[60] Maps can be used to pinpoint specific stations, and the index used to determine the extent of information obtained at the station.

At the present time, the Office of Water Data Coordination is developing NAWDEX--A System for Improving Accessibility to Water Data. NAWDEX--National Water Data Exchange--is a concept in which all water data will be stored in a central system in a form readily retrievable by computer. Descriptions of the system have been published.[21,36,37,63] The complete NAWDEX system is not yet operational. When it is, it will be an extremely useful source of water quality data.

At the present time, large quantities of water quality data are retrievable from STORET, a data bank operated by the Environmental Protection Agency. The EPA's STORET system collects data from many agencies, and is presently the most comprehensive source of water quality data. It is in computer-processible form which permits easy access. Access to the data can be gained through regional EPA offices. According to the Office of Water Data Coordination, STORET will constitute a major part of NAWDEX in the future.

Bituminous Coal Research, Inc., has published annually since 1964 a bibliography entitled Mine Drainage Abstracts. These abstracts are an important information source regarding what has been published in the area of mine drainage research and in treatment and control technology. Annual supplements published each year contain information received that year pertaining to all aspects of mine drainage. The bibliography and supplements are available at a nominal cost from the Library, Bituminous Coal Research, Inc., 350 Hochberg Road, Monroeville, Pennsylvania 15146.

(b) Sources of specific water quality information: Many areas of the country have been investigated with regard to specific pollution problems. Information in these specific studies is generally available for use to planners and engineers.

The Office of Water Data Coordination of the U.S. Geological Survey has compiled a list of such programs in the Index to Areal Investigations and Miscellaneous Water Data Activities, a fourth volume of the Catalog of Information on Water Data.56/ This index contains (1) the title of each investigation, (2) the geographic area covered, (3) the inclusive dates of the investigations, (4) description of the investigation, (5) whether or not a report will be published, and (6) the reporting agency. Thirteen federal agencies and 34 state and local agencies have activities listed in this index.

Regional Environmental Protection Agency offices are a valuable source of information and assistance to planners and engineers confronted with special problems concerning mining pollution. These offices can offer direction and assist in acquiring information from other branches of the EPA, such as the EPA National Field Investigation Centers at Denver and Cincinnati, and the Mine Drainage Pollution Control Section, National Environmental Research Center, Cincinnati.

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6.0 CONSTRUCTION

6.1 Introduction

The accelerated rise in the U.S. population through the year 2000 will require the daily development of about 1,600 hectares (about 4,000 acres)[44] of land to accommodate the expanded requirements for new housing and related services, transportation, utilities, communications, and sewer and wastewater treatment networks--all of which are construction oriented. Land areas sufficient to accommodate these new operations must be found without limiting those land and water resources needed to produce the food supplies essential to the sustenance of increased numbers of plants, animals, and man. At the present time, more than two-thirds of the U.S. population is located in urbanized areas covering 7% of the land area.

This section will identify the types of construction activities, the sources of land and water pollution associated with these construction practices, and the types of water pollutants generated during construction activities. The physical, chemical, and biological aspects of pollutant transport are discussed, and the status of methods for predicting pollution from construction activities is presented.

Emphasis is placed on the fact that environmental impacts of construction must be assessed on a site-by-site basis. As used in this section, construction activity refers to major jobs, characterized in part as heavy (as in damsites and other excavations), highway, housing developments, transmission and pipelines, dredging, and demolition operations--whether done in an urban or rural environment.[4,10] Construction practice refers to timber clearing, grubbing, and topsoil stripping; rough grading, concrete, asphalt and other facility operations; waste disposal; soil stabilization, fertilization, and revegetation; traffic control; pest control, and site restoration following construction. This term includes all job operations that generate various types of water pollutants by spillage, erosion, sedimentation, and stormwater runoff.

6.2 Types of Construction Activity

Activities likely to result in a modification of the physical, chemical, and biological properties of land and water resources include: construction of transportation and communications networks; housing; office buildings and related land developments; energy networks; water resource developments; as well as ski slopes, parks and other multiple use recreational developments.

6.2.1 Transportation and communications networks: These activities include interstate highways, roads, streets and trails, subways and railroads, and telephone lines over or under the land surface. Also included are airports, harbor facilities, microwave communication towers, radar installations, bridges, and tunnels.

6.2.2 Housing, office buildings and related developments: Included under this item are individual and high-rise housing developments, shopping centers, high-rise office buildings, schools, and industrial and commercial centers.

6.2.3 Energy networks: These include hydroelectric, fossil fuel, and nuclear power plants, and their associated electric power transmission lines, over or under the land surface. Also included are natural gas and petroleum pipelines, both above and underground.

6.2.4 Water resource development and usage: Under this item are construction activities such as dams and reservoirs, inland waterways, water pipelines, irrigation channel systems, temporary water impoundments for stormwater management, and major flood control works.

6.2.5 Ski slopes, parks and other multiple use recreational developments: Construction operations included in this category are the clearing and grading of steeply sloping ski runs, and the installation of water lines, sewer lines, power lines, and wastewater treatment facilities.[16] Also included are the construction of roads and other transportation and communications facilities contiguous to the recreational area.

6.3 Sources of Water Pollution

Construction operations are capable of generating many types of water pollutants. The amount and type of pollutants generated during construction will depend upon the type and time duration of the various construction practices, the location and size of the construction site, the rainfall distribution and frequency, pest control measures, the resistance of the soil or land surface to erosion by gravity, water, and wind, the chemical properties and geology of subsurface soils, and the number of people and machines linked with each construction site. Thus, construction of a large dam would require extensive concrete operations (aggregate processing and washing plants, etc.) within a relatively small area and in close proximity to a vulnerable waterway. Concrete operations for the construction of a highway remote from a vulnerable waterway, on the other hand, would present less severe water pollution problems.

These examples illustrate an important point: the location of the construction activity relative to environmentally vulnerable waterways, groundwater recharge areas, etc., is crucial to construction practice.

Construction practice typical of a given site will involve the following: clearing, grubbing, and pest control, rough grading, facility construction, and the restoration of staging and stockpile areas on completion of the job. These practices comprise the prime source of various types of water pollutants resulting from construction.

6.3.1 Clearing, grubbing, and pest control: These three operations may appear initially on any construction site, singly, or in combination. Their extent will be greatest in the construction of transportation and energy networks, particularly superhighways, electric transmission lines, and pipelines for oil and natural gas. Unwanted vegetation such as trees, shrubs, or tall grasses that constitute a hindrance to the development of the site will be cleared from the right of way, or the construction site. In some instances, the surface soil may be stripped and stockpiled for use during site restoration. Unwanted buildings or other man-made structures may be demolished or moved to new locations.

All of these operations can be viewed as a major disturbance of the land surface, with possible deleterious effects on the ecology of the development site, adjacent areas, and contiguous water resources.

Cutting of trees, other woody plants, and grasses can produce large volumes of timber and wood waste. Some of the timber can be converted to lumber, plywood, or pulpwood. Remnants of trees such as large branches and stumps can be converted to wood chips, buried in preselected disposal sites, or selectively burned. Special contrivances are being used in some states that allow complete burning with little or no smoke. Preparation of wood chips is the preferred method of disposal of wood wastes, because they serve as protective mulches on cut and fill slopes, access roads, and certain staging areas.

Pest control can take the form of spraying the site with insecticides, herbicides, or rodenticides, to remove insects harmful to man, herbaceous and woody plants that obstruct development, or unwanted animals.

6.3.2 Rough grading: This practice is characteristic of essentially all construction activities, with particular reference to highway cuts and fills, excavations for dams and pipelines, and housing and related land developments. Heavy construction equipment used in this practice (bulldozers and trucks) becomes both a direct and indirect source of water pollutants. Diesel fuel, oil, and lubricants are direct sources of water pollution. These petroleum products are insoluble in water and form oily films that can alter the diffusion of oxygen in the water body with harmful effects on the growth of phytoplankton and fish.

Construction equipment causes severe compaction of clayey soils, thereby curtailing the rate of water infiltration and lowering the rate of soil aeration. If these factors are ignored, the revegetation of graded areas will be considerably more difficult.

Grading results in the exposure of extensive subsoil areas which characteristically possess soil aggregates that are more easily dispersed by the impact of raindrops and wind than that of unexposed soils. Sediment particles (fine sand, silt, clay, and organic particles) caused by the erosion of soil exposed during grading is one of the most serious water pollutants. For example, up to 7.6 hectares of soil per kilometer of superhighway (30 acres per mile) may be exposed during construction. Under heavy rainfall, and the lack of proper erosion control measures, up to 1,696 metric tons of sediment per kilometer (3,000 tons per mile) can be produced. Much of this sediment (fine sand and silt) can be deposited on adjacent properties, in the smaller water bodies, and ultimately in major water bodies. Sediment deposited on the bottom of streams, lakes, and reservoirs, (fine sand and silt) threatens the survival of shellfish and other bottom dwelling aquatic species.25,32/ Clay particles of colloidal dimension that remain in suspension, creating water turbidity for long periods of time, can decrease the amount of light in the water column of lakes, and as a result decrease the rate of photosynthesis and the productivity of aquatic species located therein.

The turbidity caused by sedimentation of lakes and reservoirs can increase the absorption of heat, thereby increasing the surface water temperature relative to clear water.38/ The warmer surface water is less dense than the cold bottom water, hence it remains confined to the surface strata. If the reservoir discharges only from the surface, this warmer water may have far-reaching effects on stream ecology below the damsite.38/ Finally, pesticides and other chemicals adsorbed on sediment may be transported to lakes and streams in runoff water, where they accumulate in bottom deposits. These chemicals can be released slowly to overlying lake waters and thereby become concentrated at successive levels of the food chain.[38] Oil films may serve as a medium for concentrating water insoluble insecticides. Sediments may also serve to transport plant nutrients, primarily calcium, magnesium, and trace elements such as iron and manganese.[17] Trace metals such as copper, cobalt, and chromium are transported in rivers largely by fixation within sediment crystalline structures.[17]

6.3.3 Facility construction: This practice refers largely to core drilling, foundation grouting, and concrete operations during the construction of transmission structures, highways, buildings, and dams. Also included are dust control operations in which oil, calcium chloride, and water are used on access and haul roads, and on graded areas subjected to heavy truck traffic.

Some of these operations will be carried out directly in waterways. These include the diversion of streams necessary for the construction of cofferdams, revetments, and dikes which result in bottom deposits of sand and silt that can damage the production of shellfish and other bottom species. Finally, other operations under this heading refer to the construction of shops and storage areas, and asphalt operations.

Concrete operations are a source of pollutants through washing spillage, and waste of various materials. Large volumes of water are also used in the washing of sand and stone aggregates[8,26,30] Major pollutants include spilled cement, fuels, bituminous materials, and curing compounds. These materials may contain the trace elements cobalt, chromium, manganese, and lead which are recognized water pollutants. Facility construction activities yield solid wastes from construction camps, shops, and storage areas (including junk, scrap, trash, and sanitary wastes) which are potential water pollutants, as are insecticides and rodenticides used around the construction site.

(a) Transmission structures:[15,45] The construction of electric power transmission systems, and pipelines for natural gas, petroleum, and water will involve the use of clearing, grading, ditching, stripping of surface soil, topsoil stockpiling, stream diversions and cofferdam construction. Access and haul roads, campsites, and setup sites are an integral part of these operations. All of these practices can generate appreciable amounts of sediment and runoff.

(b) Highways, roads, and streets: The pollution sources in highway construction are essentially the same as those for transmission structures. One difference relates to the greater amount of grading, excavation of cut and fill areas, and the larger number and size of construction vehicles, and greatly increases the runoff and erosion potential of the soil surface. Highway construction is also a source of pollutants such as sediment, fuel, grease, oils, wastewater from concrete operations, concrete spillage, pesticides, fertilizers, sanitary wastes, and solid wastes.

(c) Buildings: As with the construction of highways, the construction of new buildings can have important pollutional effects on the environment. Special environmental problems in building construction refer to traffic flow around the job site, the methods of hauling and disposal of spoil and debris, time of day for scheduling demolition operations, facilities for washing concrete mixers and haul trucks, and the control of mud and sediment during construction.[22,23]

Sediment clogging of storm sewers can become a serious problem in certain housing subdivision developments, especially when curbing and storm drains are installed, and the roads are paved long before the housing is fully constructed. Thus, rainstorms impacting on exposed soils as the individual houses are built throughout the subdivision can generate sediment loads that ultimately clog the storm sewer.

(d) Dams: The construction of large dams involves many operations which can serve as sources of sediment and other pollutants during construction. Construction haul roads are potential sources of large quantities of sediment and construction related pollutants, particularly if the roads are improperly designed and contructed. Large areas of forested hillsides are often cleared and stripped to permit excavation and construction of the dam, dike, spillway, and the downstream portal of the outlet works. Also, spoil storage, and shop and equipment areas are often located at the downstream end of the dike embankment, and along the valley floor up to the center portions of the flat peninsula of the main embankment.[11] Turbid water is emitted from the dewatering of the damsite, the tunnel excavation, the batch plant, channel change areas, and downstream service yard areas. These waters become polluting waters unless they are treated in settling ponds or in clarifiers before being allowed to enter the waterway.[30] Finally, water impoundments can inundate several miles of free-flowing river and lands adjacent to the river. The nutrients, vegetative debris, pesticide residues, residues and wastes from animal life, bacteria, and mineral elements inventoried in the impoundment area automatically become sources of pollution in the impounded water. Accumulated wastes from inundated animal feedlots would, for example, provide a large initial inventory of nutrients and organic matter.

6.3.4 Site restoration: This practice refers to operations such as cleanup of the site, final grading, loosening and tillage of compacted soils, establishment of permanent vegetation, restoration of any damage to trees and shrubs caused by construction operations, removal of any temporary stream fording structures or sediment control structures, removal of temporary construction facilities such as access and haul roads, reshaping, stabilization and revegetation of borrow pit and stockpile areas, removal of office and work area structures, and any other practice that reestablishes a harmonious landscape capable of withstanding erosion by water, wind, ice, and gravity.

These operations will vary in detail from site to site, but those involving site cleanup, final grading, and the establishment of permanent trees, shrubs, grasses, and groundcovers will be carried out on any construction site, in accordance with the erosion and sediment control plan, the construction contract, and the landscape plan.

6.4 Types of Pollutants*

6.4.1 Sediment: Sediment is one of the greatest pollutants resulting from construction activity. Sediment includes solid and organic materials transported by rainfall runoff, wind, ice, and the pull of gravity. Sediment carried by the wind is usually deposited in places where the wind motion is obstructed by trees, grass and buildings--where the wind energy of motion vanishes. The magnitude of wind erosion is greatest on construction sites situated in deserts and dry soil surfaces composed largely of silt particles. Sedimentation caused by rainfall and runoff from construction sites is deposited downstream or in other receiving waters such as ponds, reservoirs, and dams. Sediment deposition occurs under some of the following conditions: when runoff carries a sediment load requiring more energy to carry than the runoff can furnish; when the runoff is intercepted by a grassed waterway, slow-flowing stream, or water impoundments such as ponds and reservoirs, and when the sediment consists of large soil particles that settle fast due to the force of gravity.

Major factors responsible for the loss of soil from construction areas include the clearing of large areas of land at one time, rather than in stages. Oftentimes the lack of a well planned grading schedule results in the exposure of surfaces during heavy rain seasons when the amount of runoff is greatest.

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* References: 3, 4, 6, 10, 18, 21, 26, 27, 30, 34, 37, 41, 43, 44, 52, 53.

Sediment has physical, chemical and biological effects on the receiving stream and water bodies. Physical damage resulting from sediment deposition includes: the reduction of storage capacity; filling harbors and navigation channels; increasing the frequency of flooding resulting in increased bank erosion; increasing suspended solids (turbidity) that reduce light penetration; increasing the cost of water treatment; damaging fish eggs and gills; destroying and covering organisms on the beds of streams; reducing the flowing speed and carrying capacity of streams; increasing the cost of maintenance through frequent dredging; destroying and impairing drainage ditches, culverts, and bridges; altering the shape and direction of stream channels; destroying water recreational areas; and imparting undesirable taste to water. Biological agents such as soil organisms, and pathogens from human and animal sanitary wastes are also carried by sediment in runoff.

6.4.2 Chemical pollutants:* Chemical pollutants are generated from various operations and materials used throughout various construction activities. Chemical pollutants originate from inorganic and organic sources. These sources may be in solid form in such construction materials as boards and fibers; and in liquid form, as in paints, oils, and glues. Organic materials have been gaining wider use in the manufacture of construction materials. The effects of the decomposition of these materials on water quality is unknown at present.

Pipes, beams, structural frames, boards, and lining materials are some of the major construction materials now being made out of synthetic organic chemicals to supplement lead, steel and iron products. Some of the major organic chemicals and products that are being used for the production of construction materials and tools include polyvinyl chloride, thermoplastic polyesters, and epoxy fibers.

Synthetic and nonsynthetic organic liquid chemicals are widely used for surface treatment of walls, sealing cracks in roofs and floors, gluing materials together, and in liquid and spray paints. Fuels are used as energy sources in construction activities. They include oils, gasoline and diesel fuel as used in trucks, power generators, backhoes, bulldozers and other construction equipment. Other organic materials used in construction activities include fertilizers, pesticides, plastics, rubbers, and curing agents.

The second group of chemical materials is derived from inorganic minerals. Mineral products provide the greater percentage of construction materials in use today. Metals, rocks, earth, and chemicals derived from minerals are widely used in the production of pipes, rods, structural frames, and construction machinery.

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* References: 1, 2, 5, 9, 13, 14, 20, 24, 31.

The major categories of chemical pollutants are: petroleum products, pesticides, fertilizers, synthetic organic materials, metals, soil additives, construction chemicals, and miscellaneous wastes--construction debris.

(a) Petroleum products: Petroleum products are the largest group of materials consumed in construction activities. Petroleum products consist of oils, grease, fuels, certain solvents, and many others. Pollutants from construction activities include crank case oil wastes, leaky storage containers, oil solvents, dust control oils, minor oil spills during transfers and transportation, oil laden rags, and degreasers.

A majority of these materials float over the surface of the water and spread easily over a wide area. It has been estimated that a gallon of oil can pollute an area of four acres. Oils and other petroleum products are readily absorbed by sediment which is the main carrier of these materials. Sediment contaminated with oil is carried in runoff to receiving streams. The inherent properties of petroleum products make them extremely difficult to control after entering water bodies.

The extent of water pollution caused by petroleum products at construction sites is dependent on the occurrence of major spills from storage tanks; the quantity of crank case oil wastes disposed of from a construction site; the number of trucks and construction equipment operated, and the state of their maintenance; and the magnitude of the construction activity. Definitive quantitative figures based on the above criteria have not been developed.

Some petroleum products impart a persistent odor and taste to water, impairing its use for drinking water and contact sports. Many oils have the ability to block the transfer of air from the atmosphere into water, resulting in the suffocation of aquatic plants, organisms, and fish. Some petroleum products contain quantities of organometallic compounds (nickel, vanadium, lead, iron, arsenic) and other impurities which can be toxic to fish and other organisms.

(b) Pesticides: The three most commonly used pesticides at construction sites are herbicides, insecticides, and rodenticides. Herbicides are used for removing weeds and other undesirable plants growing around the construction area. Their use is limited, since most plants are removed by bulldozers during land clearing and grubbing.

Insecticides are widely used on construction sites. The particular insecticide used is controlled by the geographical area, climate, and the insect type. Rodenticides are also widely used, depending upon essentially the same factors mentioned for insecticides.

Pesticides are transported to receiving waters by runoff from construction sites. Improper methods of application will result in direct contamination of water, or in drift which settles in surface waters.

(c) Fertilizers: One of the most effective means of reducing soil erosion and sedimentation from construction activities is the early establishment of vegetation on the exposed soil surfaces. The addition of commercial fertilizers promotes vegetative growth, and thus helps to prevent the loss of soil. Nitrogen and phosphorus are the major plant nutrients needed for the successful establishment of vegetation on most subsoils. Limestone is needed for the neutralization of acid subsoils exposed to the surface as a result of land clearing, trench digging, and backfilling of construction areas.

Heavy use of commercial fertilizers can add nitrogen and phosphorus to receiving waters and thus accelerate the eutrophication process.

(d) Synthetic organic materials: The construction industry utilizes many different types of synthetic products. These include structural frames, window panes, wall board, paints, and many others. Heavy duty construction materials are synthesized from nondegradable organic materials. They are little affected by biological or chemical degradation agents, and are usually designed to withstand the most severe physical conditions.

(e) Metals: The concern over metal pollution of water bodies is associated mostly with the heavy metals (mercury, lead, zinc, silver, cadmium, arsenic, copper, aluminum, iron, etc.). Metals are used extensively in construction activities for structural frames, wiring, ducts, pipes, beams, and many other uses. Construction vehicles, gasoline, paints, pesticides, fungicides, and construction chemicals are also potential sources of heavy metals pollutants. When these latter materials are weathered, decomposed and disintegrated by various agents, they ultimately form oxides and salts that can affect aquatic organisms.

(f) Soil additives: Soil additives are chemicals and materials that are applied to the soil during construction activities in order to obtain desired soil characteristics. Oftentimes construction activities cover large areas consisting of several different types of soils. The nature of soils is dependent on the climatic, topographic and geological conditions. The type of soil additive applied depends on the objectives of the construction activities. Soils may vary from one location to another in the amount of water they contain, particle size distribution (clays, silt, sand and gravel), water infiltration rate, ability to support heavy structures, and resistance to compaction by construction equipment. Soil additives are used to control the amount of moisture absorbed by roadway surfaces, to reduce the degree of shrinking and expanding of clay soils in order to prevent structural damage of buildings and air field runways, and to increase the firmness of soils.

Several chemicals and materials are used to obtain desired soil properties. Commonly used materials include lime, fly ash, asphalt, phosphoric acid, salt, and calcium chloride. The soil additives carried in runoff from construction sites alter the quality of receiving waters. However, little work has been conducted to show the net environmental effects of these soil additives.

(g) Construction chemicals: Many types of chemicals are used in construction for purposes such as: pasting boards together, sealing cracks, surface treatment, solvents for oils and paints, and dyeing and cleaning. The amounts of chemicals leaving construction sites as pollutants have not been established. Poor construction activities that are liable to contaminate water resources include the following practices: dumping of excess chemicals and wash water into storm water sewers; indiscriminate discharding of undiluted or unneutralized chemicals; disregard for proper handling procedures resulting in major or minor spills at the construction site; and leaking storage containers and construction equipment.

6.4.3 Biological pollutants:14,25/ Biological pollutants from construction include soil organisms and organisms of human and animal origin. They include bacteria, fungi, and viruses. The majority of biological pollutants are found in the topsoil layer where they can feed on dead plants, animals, birds and other organisms.

The biological pollutants resulting from construction activity that indicate the greatest pollution potential are those of animal and human origin. These biological pollutants are more prevalent on construction sites where improper sanitary conditions exist. These biological organisms can be either pathogenic (disease causing) or nonpathogenic to humans and animals. Sediments and runoff are the major carriers of these uncontrolled organisms from construction sites. Common pathogenic organisms that are significant health hazards include Vibrio cholerae that causes cholera (a major menace in societies with inadequate water supply facilities); Salmonella typhi and Salmonella paratyphi that cause typhoid fever and paratyphoid fever, respectively, and Shigella dysenteriae that is responsible for dysentery.

Sludge from wastewater treatment plants, often used as a fertilizer during the restoration of graded areas, could serve as a source of pathogenic organisms if they have survived the wastewater treatment process. The effects of sewage sludge as a source for degrading water quality is wholly dependent on the effectiveness of the prior treatment processes in destroying these harmful organisms, the quantities of sludge applied, the geographic and climatogological area, and proximity of the receiving waters to the treated area.

6.5 Methods of Pollutants Transport[9,29]

A number of agents are directly or indirectly responsible for the transportation of pollutants from construction areas to receiving streams. These include runoff, infiltration, wind, seepage, landslides, and mechanical agents. Erosion and runoff cause the greatest soil loss from construction sites. Runoff increases markedly after the rate of water infiltration is decreased. This occurs when the soil's capacity to store free water reaches a maximum. Large masses of suspended sediment resulting from exposure of soils to runoff on construction sites may be washed into waterways. Oils, trash, and other construction debris are also carried in suspension until they are deposited in receiving streams. Sediment is the most important of all the suspended pollutants carried in runoff because of its massive volume, its effects on the environment, and its difficulty of control.

Many chemical and biological pollutants generated at construction sites are adsorbed or fixed to sediments. The forces that are responsible for the transportation of sediment also affect the movement of other pollutants such as fertilizers, oils, heavy metal salts and oxides, and other construction related chemicals that are carried with sediment either in suspension or as dissolved materials. Construction-related solid wastes carried by runoff include: paper, beer cans, beverage cans, aluminum foil, and plastic wrappers. Petroleum oils form a thin film over the surface of water, and can be carried over long distances and wide areas.

A second agent for transporting pollutants is wind. Wind carries particles of contaminated soil particles and spray chemical droplets to areas far removed from construction sites. It is customary to encourage the clearing of construction sites during dry periods in order to reduce the amount of soil erosion due to runoff. This practice could encourage wind erosion if dry conditions exist for extended periods of time. Limited data exist on the quantity and effects of wind-deposited sediment derived from construction sites on receiving waters. Wind is also responsible for the transportation of insecticides, herbicides, and other pesticides that are applied as aerial sprays. These chemical pollutants are carried in air drifts to water courses and other areas where they can be toxic to nontarget plants, insects, and aquatic organisms.

Transportation of pollutants from construction by infiltration and seepage has been relatively unstudied. Construction activities close to the water table, such as construction of septic tanks or basements, can result in the infiltration of coliform bacteria and domestic chemicals to the water table. A limit of 4-8 ft of soil between septic tanks and the water table is recommended by many public works agencies as a means of controlling pollution from infiltration of sanitary wastewater.

Seepage involves the movement of pollutants from below the ground up to the soil surface. One of the oldest and most common methods of disposing of chemical and oil wastes is burial. After a period in the ground, these chemicals can be carried to the surface where they may be carried in runoff to nearby streams and reservoirs. This type of movement of buried chemicals could be severe depending on the quantities buried, the nature of the soil (very porous or nonporous) and the amount of water seeping to the surface.

The nature of the pollutants plays an important role in the degree to which they can be transported through seepage and infiltration. Dissolved solids and liquid chemicals are more likely to be transported through these processes than suspended particles. The latter have the tendency to seal off the pores necessary for the movement of water. The chemical activity of the pollutants is also important. Cations such as sodium and zinc that are strongly adsorbed by clay particles will be retained in the surface soils. Less strongly adsorbed anions such as chlorides and nitrates will more easily contaminate groundwater.

Wash water and solvents are often dumped in areas close to waterways or into sewers. It is common practice to clean concrete mixers near open gutters and storm sewers. Similar practices are common when cleaning oily hands, tools and machinery. Finally, pollutants in the construction area become dispersed widely by the movement of machinery. Spilled chemicals and crankcase wastes, for example, are subject to dispersal by movement of dozers and trucks.

6.6 Quantification of Pollution from Construction Activities

Quantification methods for pollution from construction activities are available only for soil erosion, and suspended sediment yield. Methods are not available for other pollutants such as petroleum products, construction chemicals, pesticides, etc.

The following sections present the extent of soil erosion from construction sites; erosion prediction methods; and methods for collection of data for quantification of erosion and sediment, including literature survey, field survey, and stream water quality sampling.

6.6.1 Extent of soil erosion: Construction of highways, housing developments, shopping centers, water resources projects, recreational facilities and large manufacturing centers tends to denude each year nearly 600,000 hectares (1.5 million acres)[44] of land of its soil cover, and produces huge quantities of sediments from erosion processes. Sediment is the greatest pollutant in quantity, and carries other water pollutants as well. The chemical and biological significance of these pollutants in water quality is of concern in protection of water resources. Soil erosion from construction sites is a significant environmental threat and special legislation in several states is under consideration, following the pioneering efforts of Maryland. The extent of sediment load may be appreciated by an example of the relative contributions from rural areas and from land under development in Maryland. The rural areas in the Potomac and Patuxent River Basins, under normal conditions, contribute less than 70 metric tons/km^2/year (200 tons/mile^2/year) of sediment, while land under development in this same region has been found to contribute from 354-42,350 metric tons/km^2 (1,010-121,000 tons/mile^2) per year.[42] Guy and Ferguson[19] reported that the movement of sediment from concentrated residential construction at Kensington, Maryland, might exceed 17,500 metric tons/km^2 (50,000 tons/mile^2) while the sediment movement from several "natural" drainage basins in Pennsylvania and Virginia near the Washington, D.C., area is generally less than 70 metric tons/km^2 (200 tons/mile^2) per year. In the case of the Potomac River, about 25% of the 2.27 million metric tons (2.5 million tons) of sediment dumped into the tidal estuary is produced in the immediate vicinity of the Washington Metropolitan Area, which represents only about 2% of the total drainage area of the basin.[32]

Urban construction can result in increasing the velocity of surface runoff during storms as well as increasing the amount of sediment transported. When urban construction in the Bel Pre Creek area in Maryland increased by 15% on a pasture/woodland, Yorke and Davis[52] observed that storm runoff increased 30% and suspended sediment increased

14%. They also observed a direct relationship between the amount of construction and the sediment yield of a basin.[53]

Vice, et al.,[46] reported on a study conducted in northern Virginia. They analyzed the sediment yields from 88 storm events representing overland runoff from 1961 to 1964, and showed that: (1) the mean concentration of sediment in the flow increased as the amount of flow in a given storm increased; (2) the concentration and sediment yield varied considerably depending on the area exposed during construction and how rapidly remedial measures took effect; and (3) an average of 72.5 hectares (179 acres) of construction area (6% of the drainage area) contributed 94% of the 33,500 metric tons (37,000 tons) transported from the basin during a 3-4 year period of record.

In a U.S.G.S. study of the Scott Run Basin near Washington, D.C., 85% of the sediment transported into the basin came from highway construction which covered only 11% of the 11.6 km^2 (4.5 miles^2) basin.[12] Under conditions of normal precipitation, sediment yield in the construction area would be about 16,800 metric tons/km^2 (48,000 tons/mile^2) annually. This amount is about 10 times that normally expected from cultivated land, 200 times that expected from grassland, and 2,000 times that expected from forestland.[12]

6.6.2 Prediction of soil erosion: Erosion can occur in two ways: through the effects of wind action or water movement. The transport of eroded material by wind action appears to be of regional significance; though important in arid western states, it tends to have limited impact on overall water quality. Prediction of soil loss by wind erosion in the United States has been described by Skidmore and Woodruff[33] in Agriculture Handbook No. 346 of the ARS-USDA.

Water erosion may occur in two ways: sheet erosion and channel erosion. Sheet erosion is usually associated with the removal of uniform soil layers through the action of raindrop splash and transport of loosened soil by overland flow. Rill erosion is closely associated with sheet erosion. The formation of rills indicates the concentration of overland flow and marks the transition from sheet erosion to the channel erosion process. Channel or gully erosion is normally created from accelerated erosion of rills and other depressions of the surface which tends to concentrate the surface runoff. Thus, channel erosion is created by concentrated flow. Sheet erosion represents a major mechanism for soil loss from overland flow.

The methods of predicting soil loss from cropland by sheet erosion were documented in this report under Agriculture (Section 3.0). Methods developed by Musgrave (1947), and Wischmeier and Smith (1965) are used for predicting on-site erosion of cropland in order to design adequate soil conservation practices.

(a) Musgrave equation: Musgrave[28] reported the results of analyses of soil-loss measurements for some 40,000 storms occurring on fractional acre plots in the U.S., and proposed the following empirical relation:

$$\begin{aligned} E, \text{ in } m^3 &= 12\, IRS^{1.35}\, L^{0.35}\, P_{30}^{\;1.75} \\ E, \text{ in acre in.} &= IRS^{1.35}\, L^{0.35}\, P_{30}^{\;1.75} \quad , \end{aligned} \tag{6-1}$$

where E is the soil loss, I is the inherent erodibility of the soil in centimeters (inches). R is a cover factor, S is the degree of slope in percent, L is the length of slope in meters (feet) and P_{30} is the maximum 30-min amount of rainfall, 2-year frequency in centimeters (inches). The equation (6-1) is applicable to long-range average soil losses for broad areas.

Data are not available to show the applicability of the Musgrave Equation to construction sites.

(b) Universal soil loss equation: The Agricultural Research Service of the U.S. Department of Agriculture has developed the Universal Soil Loss Equation[51] from analyses of vast quantities of data on soil losses in croplands. This equation takes into account the influence of the total rainfall energy for a specific area rather than rainfall amount. The total rainfall energy can be computed for localized areas from existing U.S. Weather Bureau data. The Universal Equation is:

$$A = R\ K\ LS\ C\ P \quad , \tag{6-2}$$

where A is the average annual soil loss, R is the rainfall factor, K is a soil-erodibility factor, LS is a slope length and gradient factor, C is a cropping and management factor, and P is the supporting conservation practice, such as terracing, strip cropping, and contouring.

Recently, Wischmeier and coworkers,[49] developed a soil erodibility nomograph for computing K factors for the Universal Soil Loss Equation for farmland and construction sites. The nomograph is shown in Figure 3-4 in Section 3.0 of this report.

The reader is referred to Section 4.0 (Agriculture) of this report and references 47-51 for information on methods of evaluating the various terms of the Universal Equation as well as the limitations of prediction with this equation.

The Universal Soil Loss Equation has been recently adapted by Swerdon and Kountz[40] for use in predicting soil loss from highway construction. Meyer[27] has summarized the use of the Universal Soil Loss Equation for predicting the annual erosion rates on construction sites, and for evaluating erodibilities with alternative land management practices. Purdue University,[7] under a grant from the Environmental Protection Agency, is attempting to modify the Universal Soil Loss Equation to include chemical and mineralogical parameters to allow better prediction of soil loss from construction activities. Other studies[36,40] have also extended the application of the Universal Soil Loss Equation to construction areas. The methods require that assumptions be made relative to the cropping management and erosion control practice factors and to the extrapolation of the slope length and gradient factors from previous results to the conditions encountered in construction. They incorporate the results of recent research[50] on the soil erodibility factor for subsoils.

Construction usually exposes soil to rainfall on slopes steeper than those found in agricultural applications, which results in greater quantities of runoff at higher velocities. This is especially true in the case of highway construction, which has been often held responsible for significant increases in suspended sediment yield in adjacent streams. Younkin[54] reported on the development of an equation that may be used for computing the suspended sediment load carried by a stream system during periods of rainfall-induced erosion of disturbed soils common to highway construction. The prediction equation of Younkin, based on a graphical multiple regression analysis of 86 sets of data from the White Deer Creek Valley drainage basin in Pennsylvania, is:

$$Q_s\text{, in metric tons} = \frac{0.0092R^{1.5}\,[\log A + 0.392]^{2.45}\,(3.32)^D}{P^{0.72}}$$

$$Q_s\text{, in tons} = \frac{0.034R^{1.5}\,(\log A)^{2.45}\,(3.0)^D}{P^{0.72}}, \qquad (6\text{-}3)$$

where Q_s is the suspended sediment yield at a stream station in metric tons (tons), A is the area of the exposed surface affected by the rainfall in hectares (acres), R is a rainfall factor in the Universal equation in metric tons/hectare/year (tons/acre/year), P is a dimensionless proximity factor, and D is the average depth, in meters (yards).

The use of the Universal Soil Loss Equation in predicting the amount of soil erosion at construction sites is demonstrated by the following example. A road is built near Covington, Kentucky, on a 4.5% slope and with a 61.6 meter (200 ft) length. The soil is Eden silty clay, and is bare of vegetation. The parameter values in the soil loss equation are

$$R = 394 \text{ metric tons/hectare/year (175 tons/acre/year)},$$
$$K = 0.28 \quad ,$$
$$LS = 0.7 \quad ,$$
$$C = 1.0 \quad ,$$
$$P = 1.0 \quad .$$

The calculated erosion rate is

$$\begin{aligned} E &= (394)(0.28)(0.7)(1.0)(1.0) \\ &= 110 \text{ metric tons/hectare/year} \\ &\quad \text{(34.4 tons/acre/year)} \end{aligned}$$

6.6.3 Methods of data collection: Information required for quantification of soil erosion and sediment production from construction sites include the location and area of construction, soil and geologic conditions, rainfall data, topographic features, hydrologic characteristics, ground cover condition, as well as suspended sediment level of the surface water. Such data can be obtained through literature surveys, on-site inspection, and stream water monitoring.

The following discussion on literature surveys and field surveys is condensed in great part from "Guidelines for Erosion and Sediment Control Planning and Implementation," EPA-R2-72-015.

(a) Literature survey: A survey of literature pertaining to erosion and sediment control at construction sites should include the use of topographic, geologic, soil, and zoning maps; aerial photographs; and publications which provide sources of information on physical features (including topography, soil, geology, hydrology, and rainfall) that relate to erosion potential of the sites. Inquiries should be made to government agencies at the federal, state, county, and municipal levels, and to private construction companies, for specific information on construction activities in the area.

Maps and aerial photographs are available from several governmental sources. An important source are topographic maps of the U.S. Geological Survey. The quadrangle maps published by the U.S.G.S. have a scale of 1:24,000 and a contour interval of 6.096 m (20 ft). These maps are valuable in studying the gross topographic features of the site.

Other important sources of maps are the state Geological Surveys. The geologic maps (state and/or county) published by these organizations display gross topographic features, and show the recognized and inferred rock outcrop areas of the various geologic units. These maps provide geologic information related to soil erosion and sediment production.

County highway, planning, and zoning maps are often available, and are useful in developing information prior to site evaluation.

Local aerial photographs are usually available at the local county soil and water conservation district office. These terrain photos provide many important features of construction sites. Stereoscopic pairs of air photos permit the viewing of the area in three dimensional perspective. As a result, landforms, vegetation features, hydrologic features, and man-made features are clearly visible.

In addition to the various types of maps, there are several publications which provide general information on local soil and geologic conditions. The most useful publications, which are readily accessible for public use are the County Soil Survey Reports. These reports, published by the Soil Conservation Service of the U.S.D.A., contain much useful information for evaluating the erosion potential of construction sites. For example, they contain photo mosaics which are superimposed on soil maps. These photo mosaics which show soil characteristics such as permeability, grain size gradations, and unified and AASHO soil classifications, can be used to extract characteristics of soils which relate to erosion and sediment production. In addition to soil characteristics, the photo mosaics also show the ground slope and major drainage patterns of the area including a delineation of flood plain soils and relative locations of roadways, woodlands, and agriculture areas.

The state and county highway departments are also important sources of soil data, particularly for subsurface information. These agencies often have records of subsoil and bedrock types, groundwater conditions, and various engineering properties of soils and bedrocks resulting from their roadway and foundation investigations.

In many states the State Geological Survey publishes water resource bulletins at the county level. These bulletins contain statistical information on the hydrology of various drainage basins in the county as well as on the groundwater characteristics of the various geologic units.

Local rainfall data, and data pertaining to rainfall-erosivity index used in the Universal Equation or the Musgrave Equation are available from the Soil Conservation Service or the Weather Bureau. For example, values of the factor "P" (2-year, 30-min storm) used in the Musgrave Equation are presented in the Weather Bureau Technical Bulletin No. 40. For factor "R," which is used in the Modified Musgrave Equation and the Universal Equation, data are given in the USDA-ARS Agriculture Handbook No. 282[51/] for states east of the Rocky Mountains, and in USDA-SCS Technical Release No. 51[36/] for the non-orographic rainfall areas in the west. Separate "R" data for orographic areas in the west are expected to be made available from SCS soon.

(b) Field survey: The field survey includes a study of soil surfaces at the development site, and an investigation of the characteristics of local geology, soil, and conditions of streams. If the construction involves extensive grading, it is also desirable to perform a subsurface study, to provide information on the geologic soil and groundwater conditions that influence the erosion hazards of the site.

Soil cover: The soil cover of construction sites is evaluated as bare ground or protected soil. Bare ground, defined as nearly totally void of vegetative cover, has a very high erosion potential. This type of soil cover will require extensive control measures to prevent erosion and sediment runoff during and after construction.

Protected ground is defined as an area covered with grass, shrubs, vines, trees, or litter. A dense cover of these materials is effective in preventing erosion on slopes, swales, and along drainage ways and impounded waters. Whenever soil erosion is evaluated, any type of cover, even if it is weeds, is considerably better than exposed earth.

Soil characteristics: The presence of highly erodible soils is a very critical physical feature, especially if these soils occur on moderate to steep slopes. It is not always possible for the layman to recognize a highly erodible soil horizon. It may be masked by a stand of vegetative cover or it may exist as a soil horizon beneath a surface soil of a different character.

Highly erodible soils are usually characterized by a deficiency of soil particles that have cohesive strength. This cohesive strength is usually a function of the clay sized (colloidal) fraction of the soil horizon. However, there is no absolute rule of thumb because soil characteristics can be variable even within the boundaries of individual soil mapping units. It is important that the erodibility of soils be evaluated; if there is any doubt professional assistance should be requested.

Stream conditions: Streams deserve a very careful evaluation when erosion and sediment hazards are examined. The streams can contribute substantially to the sediment load through channel degradation and bank erosion, and these factors must be taken into consideration in interpreting sediment concentration data as well as in calculating sediment yields from construction sites. Several factors contribute to channel degradation and stream bank erosion: the slope of the stream bed; the characteristics of soil and rock formations; restrictions in the channel; the magnitude of slug flow during rainfall or snowmelt; and vegetative cover on stream banks. Some of these are modified by activities in the watershed, including construction activities.

6.4.4 Monitoring of turbidity and suspended sediment level: The turbidity and suspended sediment data concentrations of river water have been monitored at several thousand locations throughout the United States. For some locations, historical trends are available for periods in excess of 50 years. Some of these water quality inventories are maintained by the Environmental Protection Agency, the U.S. Geological Survey, the Army Corps of Engineers, and state water pollution control agencies.

When necessary data are not available from existing sources, local water quality monitoring programs must be established to determine the extent of pollution caused by construction activities.

A good sampling program is important for obtaining accurate information to determine the impact of construction activity on suspended sediment.

Two sampling systems can be considered. In one, the program is on a short-time basis with sampling locations up- and downstream of the construction site. This system is particularly useful when the construction is confined to a small drainage basin, where the whole construction site can be treated as a contiguous unit. By comparing up- and downstream data, the impact of the construction activity on the suspended sediment yields and concentrations can be determined.

When construction activities are spread throughout a large watershed, the net pollutional effect of total construction can be determined with sampling stations located downstream of construction sites. The duration of the sampling period will in this case be extended over a longer period of time. In this circumstance, the impact of construction activities on the suspended sediment concentration can be analyzed by comparing records taken before and after construction starts. Such comparison should be made on the basis of the same stream-flow rate, since soil erosion varies with different rainfall intensity and rainfall amount.

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